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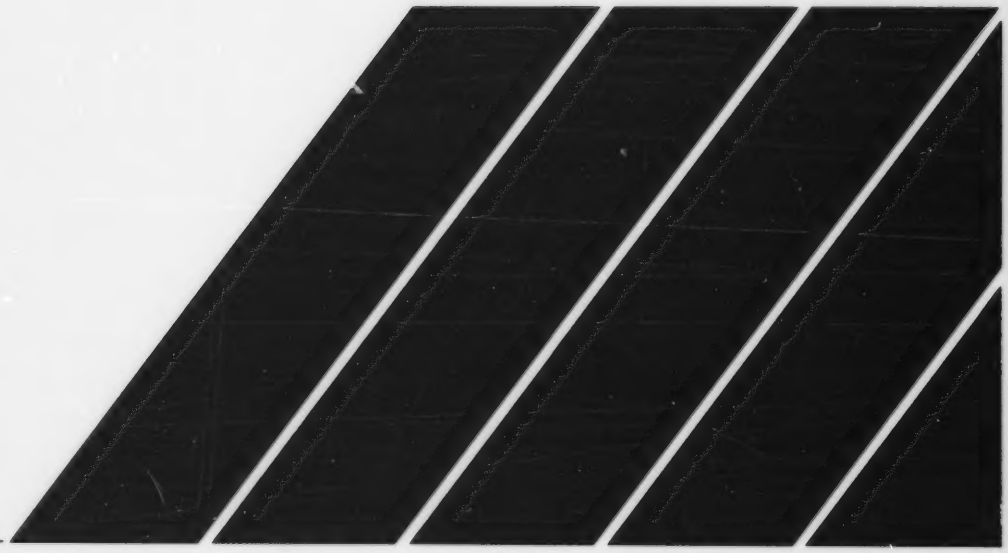
Efficiency and Alternative Energy Technology Branch

Direction de la technologie de l'efficacité énergétique et des énergies de remplacement

FINAL REPORT ON THE DESIGN, INSTALLATION, FULL-SCALE TESTING AND DEMONSTRATION OF A BULBOUS BOW AND WINGED-TYPE NET GUARD ABOARD THE FV "KYNOC"



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FINAL REPORT ON THE DESIGN, INSTALLATION, FULL-SCALE TESTING AND DEMONSTRATION OF A BULBOUS BOW AND WINGED-TYPE NET GUARD ABOARD THE FV "KYNOC"

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
March, 1990

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RÉSUMÉ

Ce projet avait pour but de montrer à l'industrie de la pêche commerciale de quelle façon l'installation d'étraves avec bulbe et de protecteurs de filet hydrodynamiques pouvait permettre de faire des économies de carburant.

Depuis plusieurs années, on effectue, au département de Génie mécanique de l'University of British Columbia (UBC), des études sur la forme de la coque des bâteaux de pêche. Les analyses réalisées par ordinateur et les vérifications de modèles portant sur diverses formes de coques de bâteaux de pêche ont révélé que l'incorporation d'étraves avec bulbe pouvait permettre de faire des économies substantielles de carburant.

En collaboration avec Shore Boat Builders Ltd., Brandlmayr Marine Ltd. a mis au point et soumis à des essais préliminaires un protecteur de filet en forme d'ailes visant à remplacer les protecteurs de filet à membrures tubulaires (<<queues de castor>>) qui sont une grande source de freinage et qui sont installés sur la plupart des senneurs de la côte ouest.

Ce projet, qui incorporait le travail de développement de UBC et Brandlmayr Marine, a été exécuté dans le cadre du programme Enerdemo. Il comportait la conception, la vérification des modèles, les essais à grande échelle, l'analyse à long terme de la consommation de carburant et la démonstration d'une étrave avec bulbe et d'une <<queue de castor>> en forme d'ailes à bord du senneur de 60 pieds <<KYNOC>> de la Sunshine Fishing Company Ltd.

Le présent rapport comprend le Rapport final sur la conception, l'installation et les essais à grande échelle d'une étrave avec bulbe et d'un protecteur de filet en forme d'ailes à bord du bâteau de pêche Kynoc (juillet 1989) ainsi que de l'information sur l'analyse à long terme de la consommation de carburant et le transfert technologique de ce projet qui a pris fin de mars 1990.

Il y a eu, dans le cadre du projet Enerdemo en cours, conception et vérification de modèles de plusieurs bulbes, pour permettre la sélection d'une bulbe optimale devant être installé et faire l'objet d'essais à grande échelle et d'une démonstration à bord du Kynoc, senneur de 60 peids appartenant à la Sunshine Fishing Company Ltd. La vérification de modèle d'une queue de castor en forme d'ailes a aussi eu lieu dans le but d'en optimiser la conception avant son installation à bord du Kynoc.

Le présent rapport sommaire et ses deux annexes contiennent les résultats de la conception, de la vérification de modèles et des phases d'essais à grande échelle du projet.

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PART B

Part A

FINAL REPORT ON THE DESIGN, INSTALLATION, FULL-SCALE TESTING AND DEMONSTRATION OF A BULBOUS BOW AND WINGED-TYPE NET GUARD ABOARD THE FV "KYNOC"

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
March, 1990

Funding for this project was provided
under the Enerdemo Program.

1.0 INTRODUCTION

The purpose of this project was to demonstrate to the commercial fishing industry how fuel savings could be achieved through the installation of bulbous bows and hydrodynamic net guards.

Studies on fishing vessel hull forms and ways to imrove their efficiency have been conducted at the Department of Mechanical Engineering, University of British Columbia, for several years. The results of computer analysis and model testing of various fishing vessel hull forms have indicated that substantial fuel savings could be achieved through the incorporation of bulbous bows ,.

Brandlmayr Marine Ltd., in association with Shore Boat Builders Ltd., developed and carried out preliminary tests of a winged-type net guard to replace the high drag pipe frame net guards ("beaver tails") installed on most west coast seiners.

Incorporating the development work of UBC and Brandlmayr Marine, this project, carried out under the Enerdemo program, involved the design, model testing, full scale trials, long term fuel analysis, and demonstration of a bulbous bow and winged-type beaver tail aboard the 60 foot seine vessel "Kynoc", owned by Sunshine Fishing Company Ltd.

This report incorporates the **Final Report on Design, Installation and Full Scale Testing of a Bulbous Bow and Winged-Type Net Guard Aboard the FV "Kynoc"** (July 1989), along with the long term fuel analysis and technology transfer aspects of the project, completed in March, 1990.

2.0 DESIGN

2.1 BULBOUS BOW

Design optimization for a bulbous bow, suitable for the "Kynoc", was carried out by Pacific Marine Technologies Inc. An initial side bulb design was generated which would result in a 6% reduction in hull resistance. In view of the much greater resistance reductions obtained during earlier tests of the UBC parent hull, optimization was continued to obtain a bulb design wich would achieve at least 10% savings. The resulting design presented a fairly radical profile so the decision was made to produce models of both the computer generated bulb and a modified version with a less severe profile.

As a result of the model testing program, described later in this report, it was necessary to abandon the sidebulb design and continue further model testing to optimize a standard bulb for full scale demonstration aboard the "Kynoc".

2.2 WINGED-TYPE NET GUARD (BEAVER TAIL)

The winged-type beaver tail design was provided by Brandlmayr Marine, based on earlier designs which had been tested to a very limited degree aboard a small seiner. This design was model tested for comparison against a standard beaver tail, resulting in further design changes by Brandlmayr Marine for an improved version to be installed aboard the FV "Kynoc".

3.0 MODEL TESTING

Model testing was carried out at the B.C. Research Ocean Engineering Centre. A detailed report on the model testing phase is provided in the B.C. Research Final Report, **Model Tests of the "Kynoc", A Hull Optimization Program**, prepared by G. Roddan, provided under separate cover with the Pacific Fisheries Research & Development Ltd. report of July, 1989.

3.1 SIDE BULBS

Both versions of the side bulb generated during the design phase produced flow separation near the hull with no overall reduction in resistance. Several modifications were made, but further testing resulted in no significant improvements. It was determined, contrary to the computer predictions, that the side bulb was not compatible with the "Kynoc's" hull form.

3.2 STANDARD BULBS

Work then commenced on the testing of two standard bulb configurations, designed so that the vessel's regulation length and anchoring operations would not be affected. These designs produced better flow patterns, but achieved no measurable resistance reduction over the unmodified hull. Further designs, with no length restrictions, were tested and optimized to produce a final bulb design which achieved a reduction in resistance of approximately 22% at 9 knots in comparison with the original bow, in the light running condition. In the loaded condition, the decrease in resistance of 6.5% at 9 knots was much smaller, but of much less importance as the vessel normally operates in the light condition. A more uniform wake distribution was also produced by the bulb. As a result, this bulb was selected for further testing and installation aboard the "Kynoc".

During sea keeping tests conducted with the selected bulb it was found that the behaviour of the vessel was improved, with reductions of added resistance, pitch, and vertical bow acceleration in head seas.

3.3 BEAVER TAIL

Self-propulsion tests were performed on the model with the selected bulb to compare the resistances of the winged-type beaver tail versus the conventional pipe frame version. The hydrodynamic winged version achieved a 22% saving in shaft horsepower over the conventional model at 10 knots. These results appeared to be compatible with the limited tests conducted earlier by Brandlmayr Marine on the small seiner.

4.0 HULL MODIFICATIONS TO FV "KYNOC"

4.1 BULBOUS BOW

The full scale version of the selected bulb was fabricated at Shore Boat Builders Ltd. and installed aboard the "Kynoc" at Progressive Marine Ltd. Costs for the bulb installation were as follows:

- fabrication, Shore Boat Builders Ltd.	$10,800
- installation, Progressive Marine Ltd.	3,786
	$14,586

4.2 BEAVER TAIL

Based on the earlier trials and model test results of the winged-type beaver tail, Brandlmayr Marine Ltd. developed an improved design and the decision was made to install this newer version onboard the "Kynoc".

Fabrication and installation of the beaver tail was completed at Progressive Marine.

Costs for the beaver tail were as follows:

- design & installation coordination Brandlmayr Marine Ltd.	$ 700
- fabrication & installation Progressive Marine Ltd.	11,091
	$11,791

5.0 FULL SCALE TESTING AND MONITORING

The full scale testing and monitoring phase of the project was conducted by the Department of Mechanical Engineering, University of B.C. A detailed report on the testing program, **Full Scale Instrumentation and Testing of the Fishing Vessel "Kynoc"**, prepared by John Avis and Dan McGreer, UBC Mechanical Engineering, was provided as an appendix to the Pacific Fisheries Research & Development Report of July, 1989.

5.1 MONITORING EQUIPMENT

To measure fuel consumption and relevant parameters , a Microfuel Systems Inc. EMS1000 Fuel Management System was installed in the "Kynoc" along with a torque meter and data aquisition system provided through UBC.

The fuel management system was installed and calibrated in February, 1989, in time for use during the 1989 roe herring fishery. The system performed satisfactorily, and through the direct fuel consumption information available, the owner felt that annual fuel savings of approximately $3,000 to $4,000 could be achieved through the use of this equipment alone.

5.2 FULL SCALE TESTS

5.2.1 Hull Without Modifications

Prior to installation of the bulbous bow, the vessel's hull, fitted with a standard pipe frame beaver tail, was docked and cleaned. Speed trials of the "Kynoc", in her normal light condition, were then conducted over a measured half-mile section of the Fraser River and measurements taken with the fuel meter and torque meter. The results of these trials are presented in Figures 1 and 2, provided from UBC, and show good comparison with the computer predicted fuel consumption for hull without bulb, in Figure 3, also provided through UBC. It should be noted that the computer generated results do not take into account the pipe frame beaver tail.

5.2.2 Hull With Standard Bulb

Immediately following installation of the bulb, speed trials were again conducted on the Fraser River with the "Kynoc" in the light condition. The results are shown in Figures 1 and 2 and again show good comparison with the computer generated results in Figure 3. In all cases tested, as reported by UBC, the fuel consumption rate at a fixed speed was less for the hull with bulbous bow than for the original hull. It should be noted that a pipe frame beaver tail was fitted for both hull configurations. At 9.5 knots fuel consumption was reduced 13% as a result of the bulb installation.

5.2.3 Hull With Bulb and Winged-Type Beavertail

On completion of the installation of the new beaver tail, a final series of full scale trials was conducted on the measured half-mile. The results are again shown in Figures 1 and 2, but there is no computer generated data of the hull with beaver tail for comparison.

Through the addition of the hydrodynamic, winged-type beaver tail, the fuel consumption at 9.5 knots was reduced a further 12% giving a total fuel saving of 23% at this speed.

6.0 LONG TERM FUEL CONSUMPTION ANALYSIS

Through the use of the Microfuel Systems Inc. fuel management system, fuel consumption was monitored from August 1989 to February 1990. While the fuel management system was able to record the vessel's position and speed over the ground from Loran C data, it did not have the facility to record the vessel's speed through the water. This prevented proper analysis of fuel consumption versus speed in the loaded and light conditions. The data for the vessel in the light condition does, however, compare favourably with the full scale trials data. Further information on this aspect of the project is included in Appendix A, **Analysis of Fuel Meter Data from FV "Kynoc"**, by Dan McGreer, P. Eng.

7.0 ECONOMIC ANALYSIS

Based on the full scale trial data, which appears to be supported by the long term fuel consumption data, a simple economic analysis can be made to estimate the vessels fuel savings and payback for the installation costs of the bulbous bow and the winged-type beaver tail. It should be noted, however, that these trials were conducted over short periods of time in a short section of the Fraser River, under fair weather conditions. Predictions made on the trials may not accurately reflect the annual fuel savings that will be obtained during fishing operations under varying weather and sea conditions, so a reduction factor of 80% was used in the analysis.

With an annual fuel bill of approximately $30,000 a projected payback of the bulb and beaver tail installations can be calculated as follows:

Projected Annual Payback

estimated average speed	9.5 knots
fuel saving @ 80% of 23% (allowing for varying operational conditions)	18.4%
bulb installation	$14,586
beaver tail installation	11,791
total cost	$26,377
annual fuel cost savings 18.4% x $30,000	$5,520/year
simple payback = $\frac{\$26,377}{\$5,520/yr}$ = 4.78	5 years

It is possible that the fuel savings may more closely approximate the 23% figure obtained during the trials, and that future installations for similar vessels may have a lower capital cost which would result in a shorter payback . It should be noted that in the case of trawlers, and combination seiner/trawlers, with longer operating seasons and much larger fuel bills, the payback period would also be improved.

8.0 TECHNOLOGY TRANSFER

Technology transfer aspects of the project results have included the preparation of a video cassette, presentation of technical papers at seminars and workshops, and the preparation of a fact sheet for distribution to industry.

During the first meeting of the International Fisheries Optimization Working Group, held at the University of British Columbia, August 28th to 30th, 1989, four papers related to the Kynoc Project were presented. Three of these papers are included as Appendices B to D and are listed as follows:

Application of a Bulbous Bow to a Fishing Vessel, by Dr. S.M. Calisal and D McGreer, University of B.C.

Reducing Added Resistance of Fishing Boats Using A Bulbous Bow, by J. Avis, Wartsila Marine Inc.; B. Dunwoody, University of B.C.; and D. Molyneux, National Research Council.

Design and Testing of Beavertail Netguards on West Coast Drum Seiners, by Don Schroeder, Brandlmayr Marine Ltd.; and G. Roddan, B.C. Research.

The fourth paper was the **Final Report on Design, Installation and Full Scale Testing of a Bulbous Bow and Winged-Type Net Guard Aboard the FV "Kynoc"** (July 1989), prepared by Pacific Fisheries Research & Development Ltd.

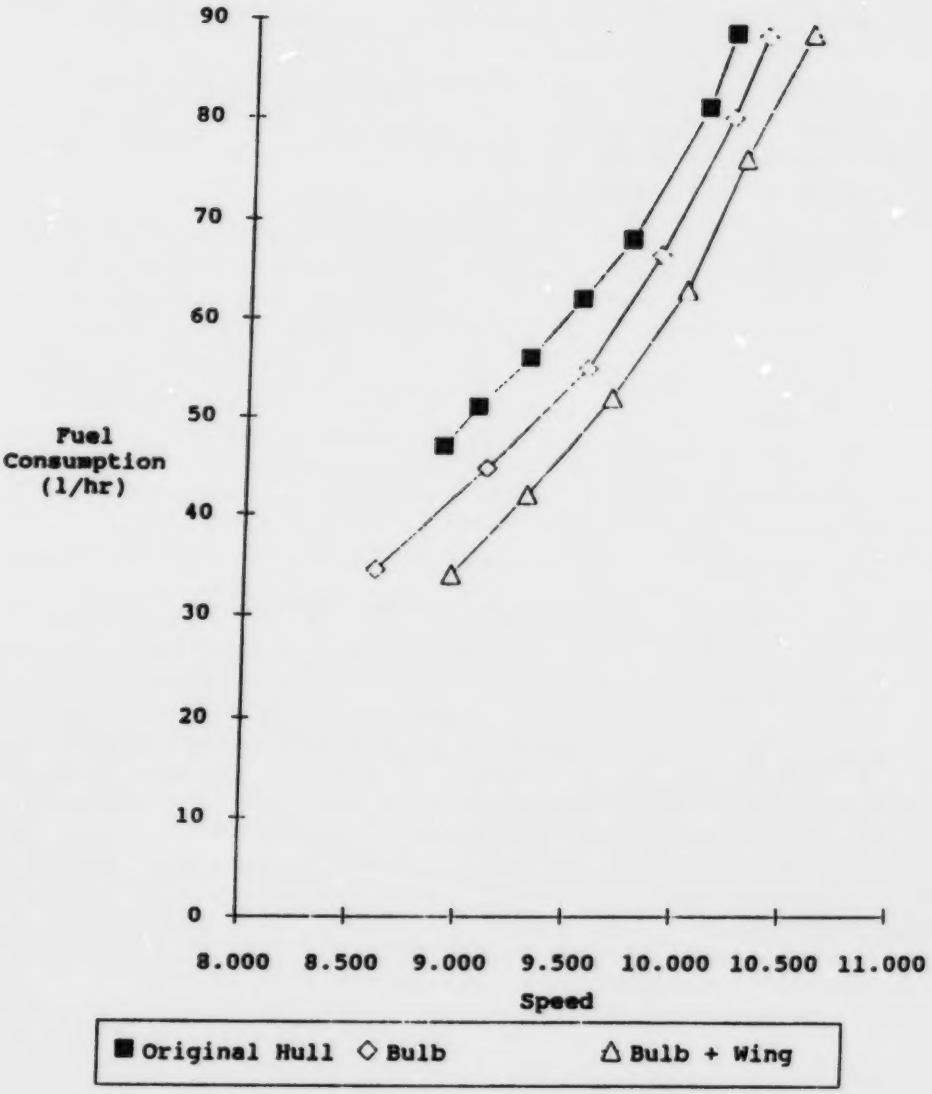
The paper by Calisal and McGreer was rewritten and presented at the CSME Mechanical Engineering Forum 1990, under the title **Installation and Testing of A Bulbous Bow on a Canadian Fishing vessel** This paper is included as Appendix E.

Information on the Kynoc Project was again presented at the **Fishing Vessel fuel Efficiency Workshop**, held at the University of B.C. on 13 March 1990. The video presentation **The Kynoc Case**, produced by Vancouver Cinecom Associates Ltd., was first screened at this workshop. As a result of this showing, some modifications were made to the video, which is now available in its final version.

A brochure on the project has been completed, ready for printing by the Farmhouse Writers Ltd.

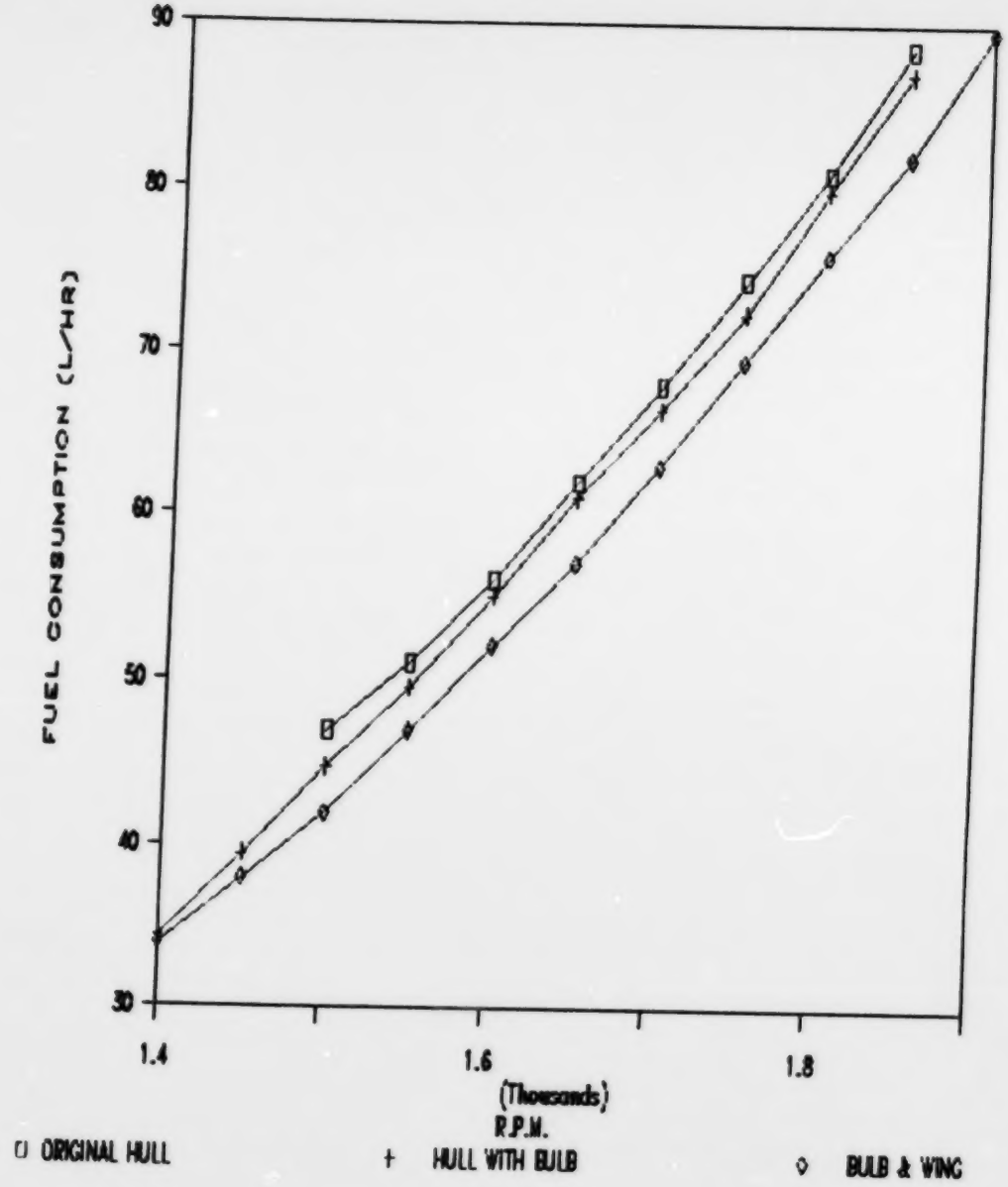
9.0 CONCLUSIONS

The results obtained during the project considerably exceeded the initial expectations in terms of energy savings,and have drawn much interest from people involved in the construction and operation of fishing vessels. As a result of the industry workshop held at UBC, initial interest has been shown by several vessel owners in installing bulbous bows on their vessels. A number of beaver tail retrofits have been completed and manynew vessels are being fitted with the new type of beaver tail. It is anticipated that with more widespread dissemination of the project results through the video cassette and the brochures, that bulbous bows will become more common and that the winged-type beaver tail will become the norm on new drum seiner hulls.



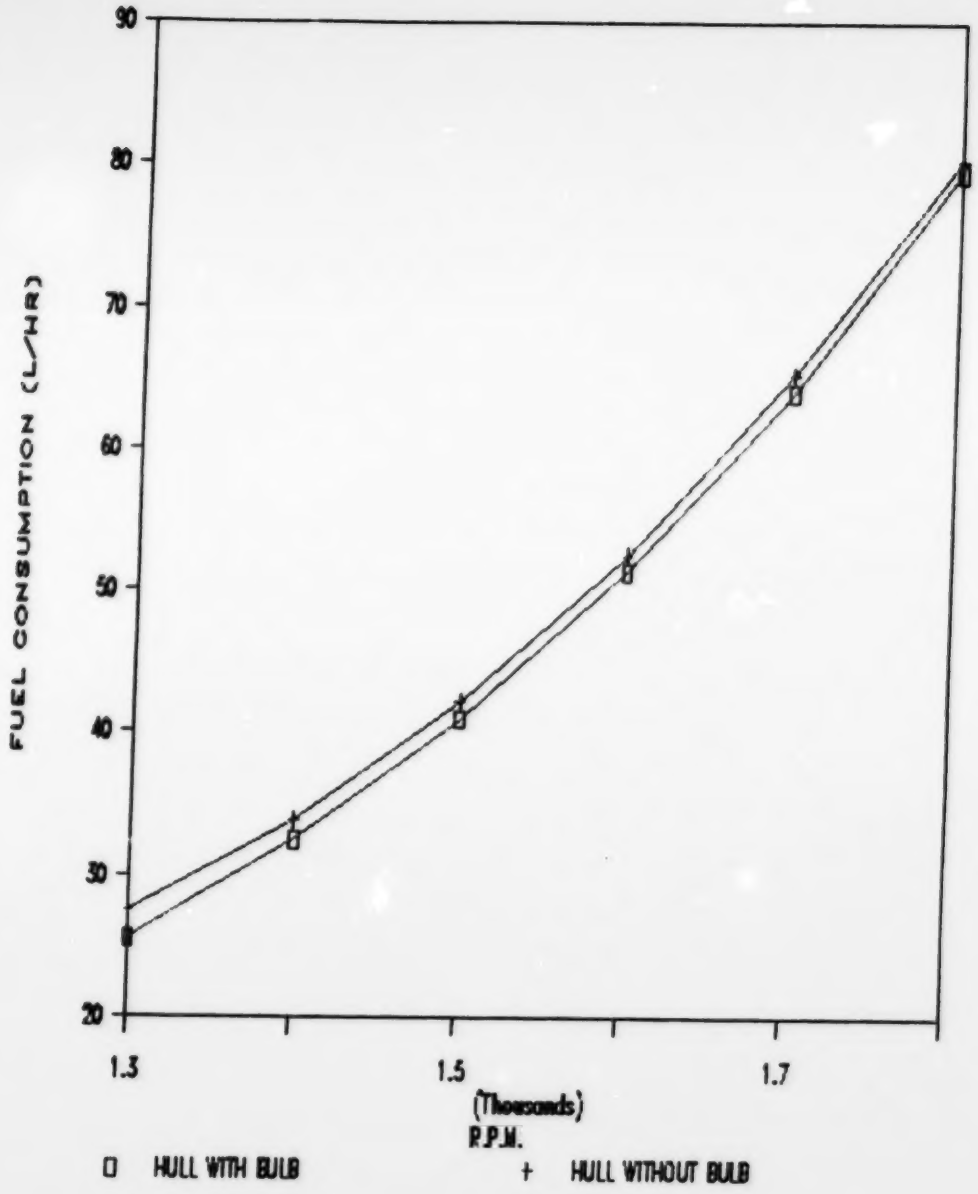
Fuel Consumption Versus Speed
Full Scale Trials

Figure 1



Fuel Consumption Versus RPM
Full Scale Trials

Figure 2



Fuel Consumption Versus RPM
Computer Prediction

Figure 3

APPENDIX A

Analysis of Fuel Meter Data from FV Kynoc

by Dan McGreer P Eng.
for Pacific Fisheries and Development Ltd.
March 25, 1990

Introduction

This report summarizes data obtained from the Microfuel Systems fuel management computer installed on the fishing vessel Kynoc to evaluate the performance of a bulbous bow and wing beaver tail. The computer was installed as part of an EnerDemo project funded by Energy Mines and Resources and managed by Pacific Fisheries Research and Development Ltd.

The fuel management computer was installed on the Kynoc before the bulb and wing beaver tail were installed. A series of trials were conducted by UBC Mechanical Engineering Department on a half mile course in the Fraser river. These trials were conducted before and after the addition of the bulb and then after the replacement of the pipe beaver tail with a wing beaver tail. The controlled trials showed that Kynoc with bulb had a 13% less fuel consumption at a typical cruising speed of 9.5 knots. When the pipe beaver tail was replaced by the wing beaver tail a 12% reduction in fuel consumption was recorded.

The fuel management computer displays; RPM, speed, fuel consumption and exhaust temperature. These values are also stored into the memory of the computer every 5 minutes while the computer on. The time, date, latitude, and longitude, and heading are also recorded each 5 minutes. It was hoped that this data could be used to evaluate the performance of the modifications to Kynoc in typical operating conditions on fishing trips.

Data Analysis

The data recorded by the fuel management computer is stored in RAM memory in computer and can be downloaded to a IBM PC compatible computer when required. The memory has a capacity of 6767 records. The data was downloaded in February 1990 by Microfuel Systems and printed. The data contained records for the period Aug 31/1989 to Feb 7/1990. Many of the data records were logged when the vessel was anchoured and the fuel meter was left on and thus approximately 40% of the data was not very useful. Microfuel Systems has now modified their software so that the computer will not log data if the engine is not running.

The latitude and longitude data were used to determine the destinations of the 5 fishing trips recorded:

- Steveston to Port Renfrew and return (San Juan on graphs)

- Steveston to Discovery Passage and return

- Steveston to Johnstone Strait and on to Rivers Inlet and return

- Steveston to Juan de Fuca (of Carmanah Pt.) and return

- Steveston to Campbell River and return

The download software did not have the capability to dump the data to a file for further data analysis. Microfuel Systems gave UBC the source code to their download software and it was modified to write the data to a file. The software is written in Turbo BASIC and it may be possible for UBC to use the software to download the fuel management computer in the future. A program was written to translate the file to a format that could be loaded into spreadsheet programs. The data set was analyzed and plotted using MS Excel.

The data is presented in figures 1-6. The data is mainly from the first trip recorded from Steveston to Port Renfrew as it is typical of the data recorded. Figure 1 gives the vessel's speed in knots versus time of day in hours. The speed is measured by the Loran-C instrument on the bridge which is connected to the fuel management computer. The speed is measure over the ground and not through the water. Currents greatly effect the ground speed as can be seen in figure 1. The speeds are quite variable even though the engine RPM was generally constant. On this trip Kynoc would have travelled down the Fraser river, through the Gulf Islands and around Race Rocks. It would not be unusual to encounter currents of 5 knots or more in those areas and about 1-2 knots in Georgia Strait and Juan de Fuca Strait. Bill Wilson the skipper of the Kynoc would likely have planned his trip to take advantage of favorable currents especially in areas where currents are strong. On this trip the engine RPM averaged 1850 and the speed averaged 10.7 knots. This is about what was obtained from the trials. The average speeds from the other trips are generally higher indicating that Kynoc took advantage of favorable currents.

Figure 2 shows the speed versus time on the return trip from Port Renfrew. Presumably the vessel was loaded with fish however that is not known. The average speed is lower at 8.5 knots and the average engine RPM is about 1650 on the return trip. Again the speed is variable even though the engine RPM was usually constant. Figure 3

has the speed versus engine RPM. This graph clearly shows how at a given engine RPM a wide range of speeds were obtained. An effort was made to group all the data from the 5 trips into increments of 10 RPM and average the data in each increment. This did not remove the effect of current from the data. This is probably because; there weren't enough data points, on average current was probably favorable and when Kynoc was in a favorable current the engine RPM was reduced and therefore the through water speed was reduced. The average speeds for many of the lower RPM ranges were often greater than that of the maximum RPM.

Without accurate speed data it is impossible to accurately compare the merits of the bulb and wing beaver tail. The trials found that the main effect of the addition of the bulb and change of beaver tail was an increase in speed at a given engine RPM. At a given RPM the percentage change in power required and fuel consumption were smaller than the percentage change in speed.

Figure 4 gives engine RPM versus fuel consumption. The fuel consumption is only slightly greater for a given RPM when the vessel is returning loaded with fish. This graph shows why it necessary to have the speed data to compare fuel consumption since when compared on a RPM basis the fuel consumption does not appear significantly different. In figure 5 the fuel consumption versus speed is shown. In this graph it is clear that loaded the vessel achieves a lower speed for a given fuel consumption. Also on this graph are the results from the trials. In the trials Kynoc was in the light condition as can be seen from the graph the light condition points seem to agree with the trials results. The scatter of the points due to the current is quite large however.

Finally, figure 6 shows the fuel consumption versus speed for another of the trips. The results agree well with the trials for most of the points however some of the points deviate up to 5 knots.

It was planned to compare the downloaded data with data which had been previously downloaded before the addition of the bulb and wing beaver tail. This data however has been lost by Microfuel Systems. If this data were found however it would be very difficult to compare the performance of the modifications to the vessel due to the problems previously stated with the measurement of speed.

Conclusions and Recommendations

Analysis of the data from the Microfuel System fuel management computer on the FV Kynoc show that it is very difficult to use the fuel meter data to find the fuel consumption versus speed in actual operating conditions. This is due to the fact that the fuel meter measure speed using Loran-C and therefore records ground speed rather than through water speed. The ground speed is greatly effected by currents and it was not possible to satisfactory average the effects of the current out of the data. Plots of fuel consumption versus speed did show reasonable agreement with the trials conducted on the Fraser river for a majority of the data points despite the large scatter caused by currents.

It is recommended that if further data logging is conducted that a knotmeter be included in the instruments recorded by the fuel management computer.

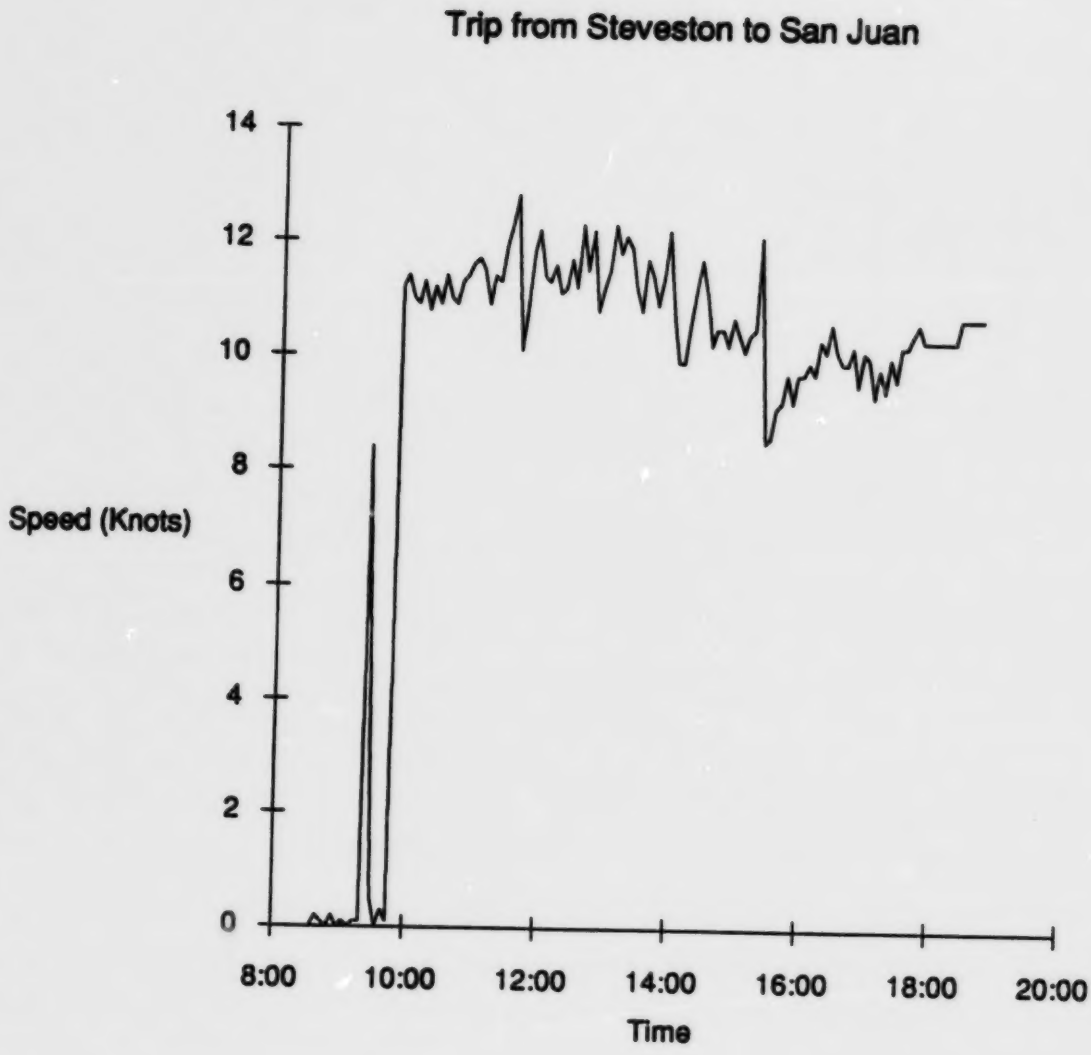

Trip from Steveston to San Juan
Speed (Knots)
14
12
10
8
6
4
2
0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
Time

Figure 1

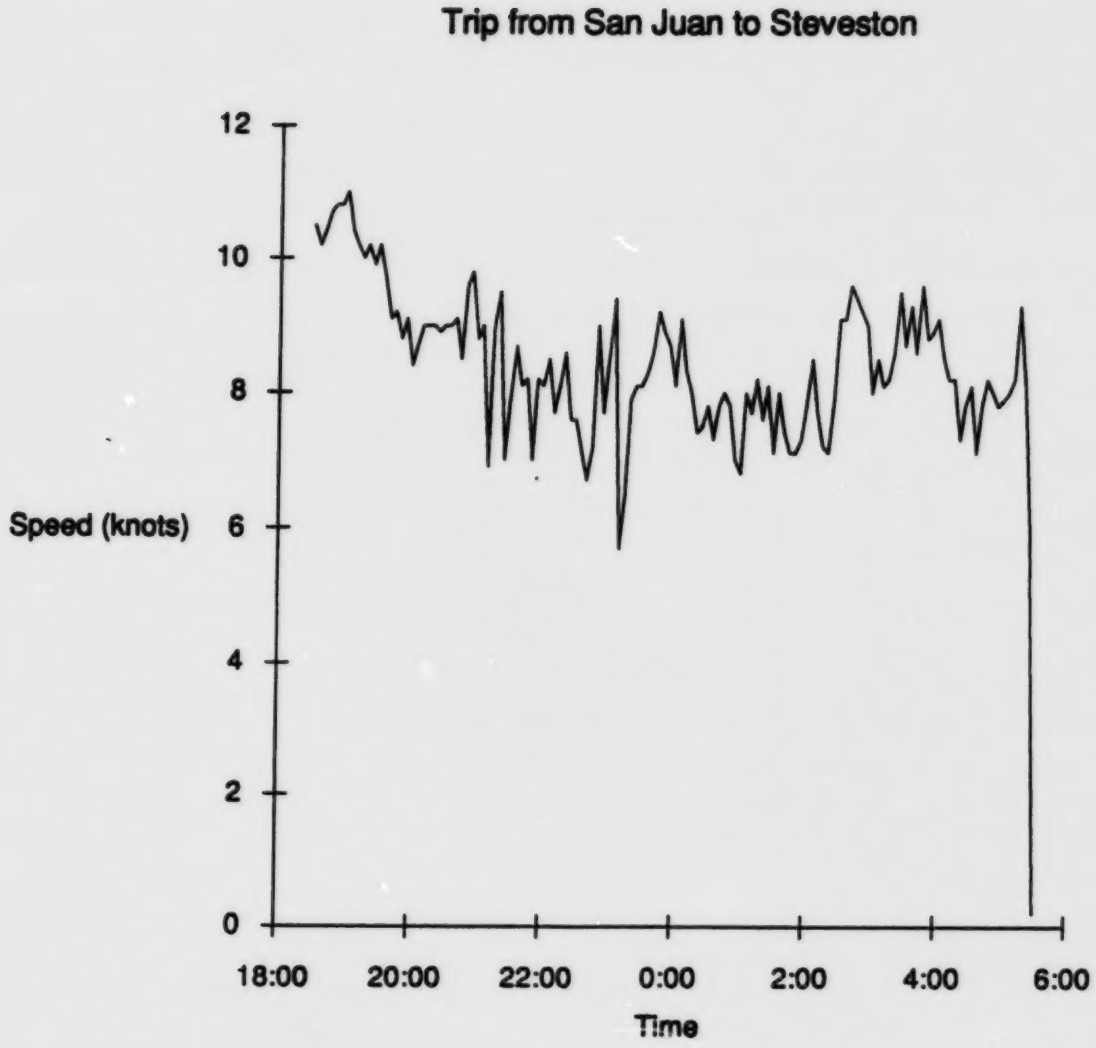

Trip from San Juan to Steveston
Speed (knots)
12
10
8
6
4
2
0
18:00
20:00
22:00
0:00
2:00
4:00
6:00
Time

Figure 2

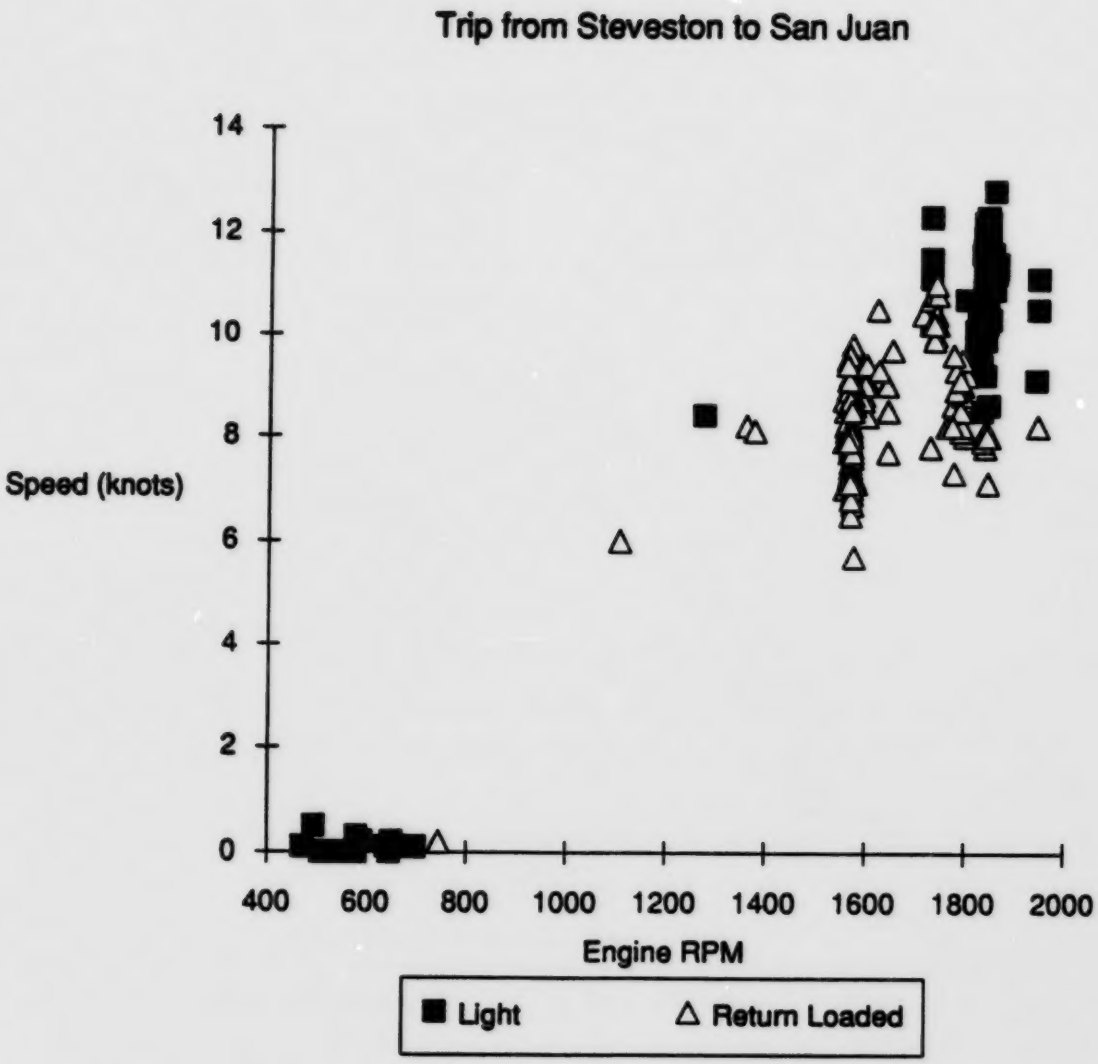

Trip from Steveston to San Juan
Speed (knots)
14
12
10
8
6
4
2
0
400
600
800
1000
1200
1400
1600
1800
2000
Engine RPM
Light
Return Loaded

Figure 3

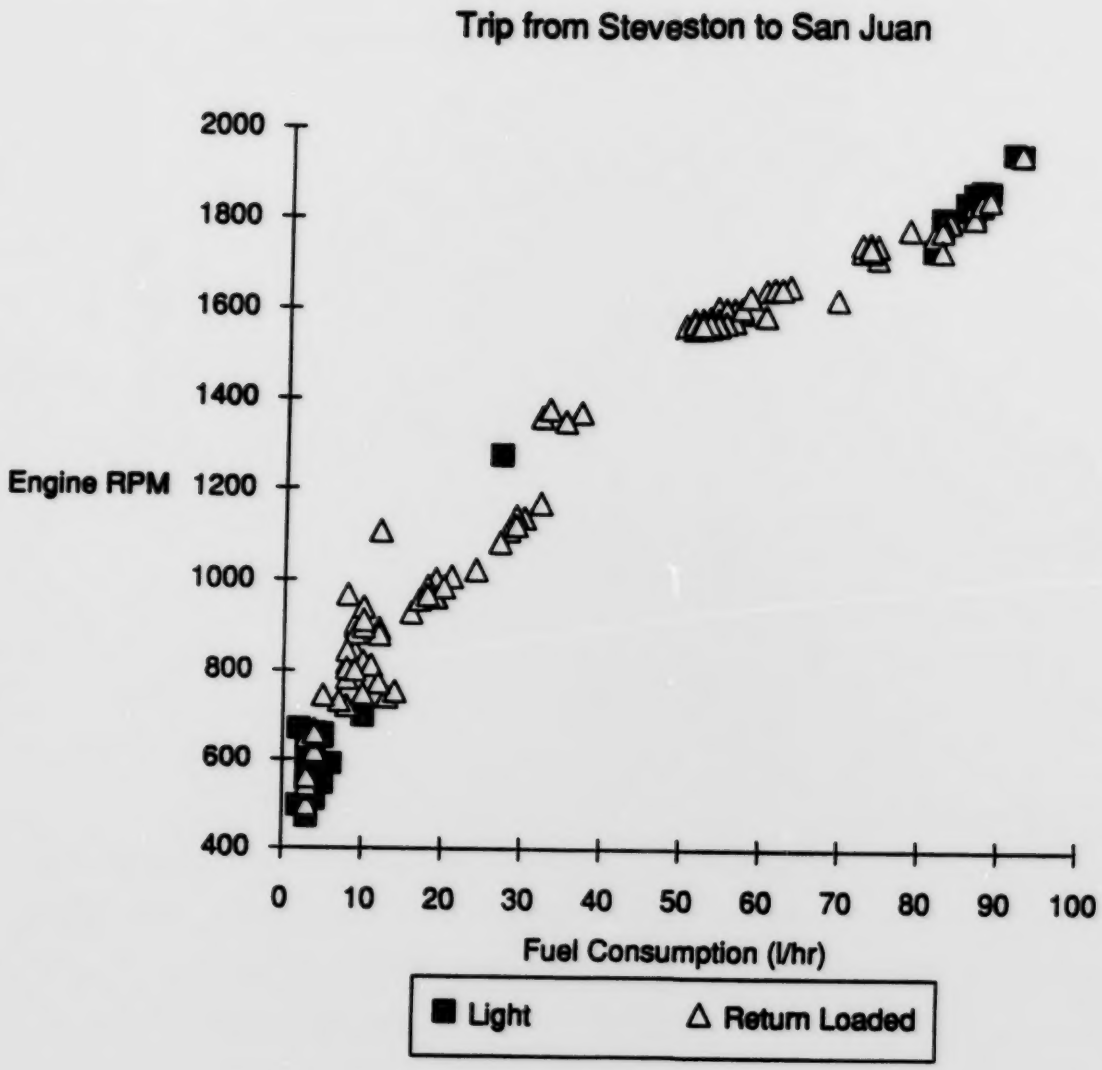

Trip from Steveston to San Juan
Engine RPM
2000
1800
1600
1400
1200
1000
800
600
400
0
10
20
30
40
50
60
70
80
90
100
Fuel Consumption (l/hr)
Light
Return Loaded

Figure 4

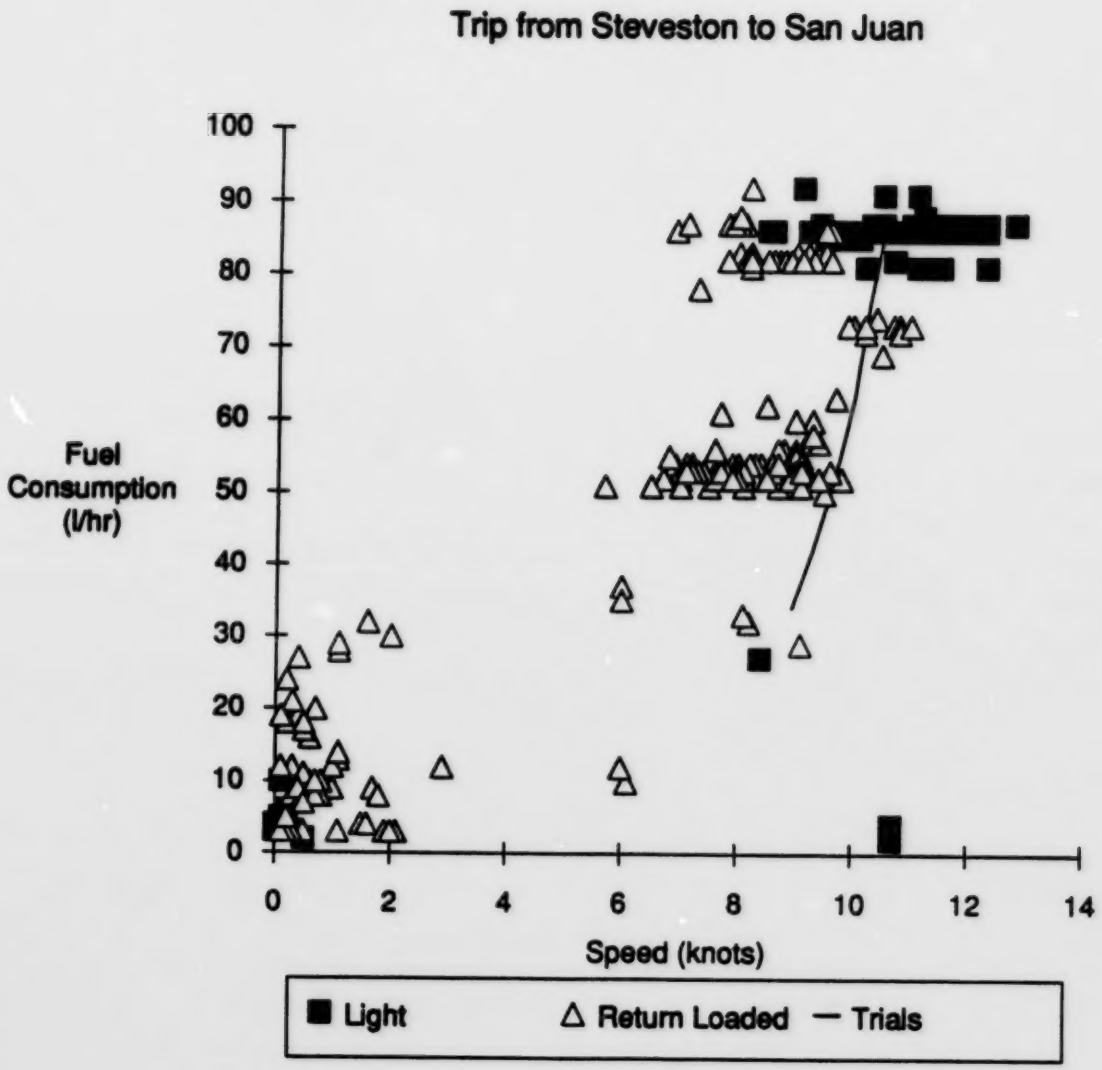

Trip from Steveston to San Juan
Fuel Consumption (l/hr)
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
Speed (knots)
Light
Return Loaded
Trials

Figure 5

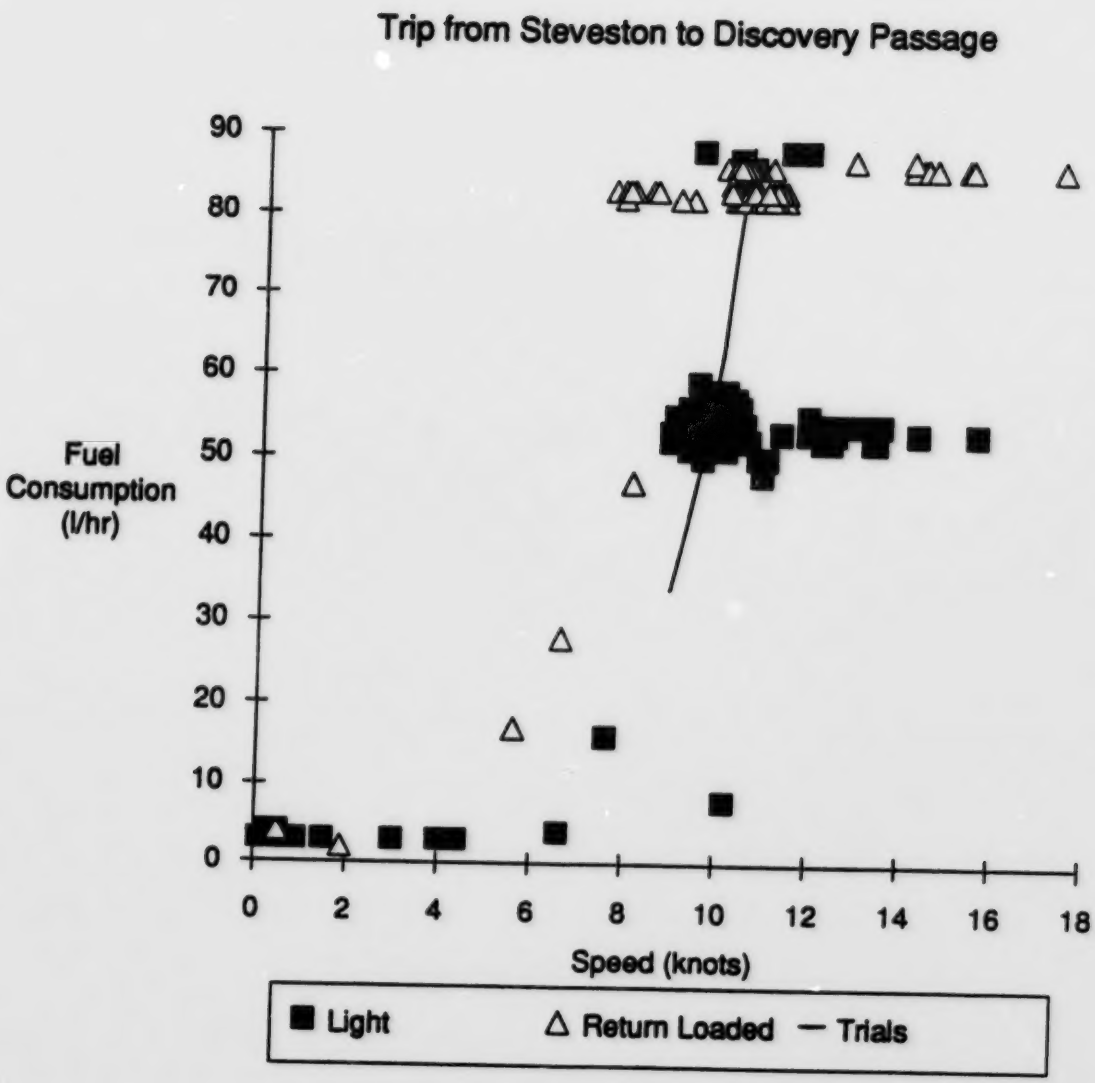

Trip from Steveston to Discovery Passage
Fuel Consumption (l/hr)
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
Speed (knots)
Light
Return Loaded
Trials

Figure 6

APPENDIX B

APPLICATION OF A BULBOUS BOW TO A FISHING VESSEL

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ABSTRACT

A bulbous bow has been installed on the fishing vessel *Kynoc* resulting in a reduction in fuel consumption of 13%. Model tests for 3 side bulbs and 3 cylindrical bulbs are presented. The side bulbs were found to reduce the wave resistance; however, the total resistance was not reduced due to an increase in viscous drag. The largest cylindrical bulb was found to have the greatest reduction in resistance and was selected for installation on *Kynoc*. Full scale trials were conducted before and after the bulbous bow addition to confirm the results on the actual vessel.

1. INTRODUCTION

Previous model testing at UBC on fishing vessel forms has shown that seiners can benefit from the addition of a side bulb (Calisal, 1988). A side bulb is similar to conventional bulbous bow except that it protrudes to the side rather than forward as with a conventional bulb (see figure 2). Seine fishermen prefer such a design since it is thought less likely to snag the seine net and does not increase the length of the vessel which is restricted by fishing licence regulations. The previous model experiments conducted on the UBC seiner series indicated about a 15% reduction in resistance at 10 knots.

To demonstrate the potential of a side bulb to fishermen, an EnerDemo project was initiated to install aside bulb onto an existing fishing vessel. The vessel chosen for the bulb installation was the 60 foot drum seiner *Kynoc* designed by John Brandlmayr Ltd. (see figure 1). The vessel is three years old and typical of seiners currently being built. New vessels tend to have low length-to-beam ratios of about 3 and high displacement-length ratios.

Two side bulb shapes were calculated by a computer program developed at UBC (Calisal, 1988). The program used a hull form optimization technique developed by Hsiung (1984) to minimize the total resistance a ship by optimizing the hull shape in the bow region. A 1/8 scale model was constructed with movable bow section. The original bow and the two side bulbs were then resistance tested. When the side bulbs did not meet expectations, three conventional bulbous bows were constructed in addition to another side bulb design.

This paper gives the results from calm water resistance tests, wave cut analysis, and full scale trials. Other tests were conducted on sea keeping and self-propulsion which are reported in other papers at this workshop (Dunwoody, 1989; Roddan & Schroeder, 1989).

2. SIDE BULB TESTS

The mathematical methods used to develop the side bulb designs are described in reference (Calisal, 1988). Briefly the method optimizes an objective function which is the sum of the frictional resistance and the wave resistance. The frictional resistance is calculated by the ITTC-57 flatplate formula and the wave resistance is calculated by Michell's Integal. A resistance equation that is a function of the hull offsets results from the use of tent functions to approximate the hull. This allows standard mathematical procedures to be used to find the offsets that will give the minimum resistance. Constraints are used in the optimization to limit the offsets to practical values.

Side bulb 1 was developed with the constraints given in table 1 (figure 2). The program predicted a 10.8% reduction in total resistance. The offsets were faired by hand and a 1/8 scale wooden model was constructed. A second side bulb, with smaller waterline slopes after the bulb was also constructed (figure 3).

Resistance tests were conducted at the BC Research & Ocean Engineering Centre (Roddan, 1989). The model was free-to-trim and free-to-heave. Resistance, trim and sinkage were measured at speeds from 4 to 12 knots. The model was tested at two displacements: 82.3 L.T. and 139 L.T. The lower displacement is typical of the light running condition and the higher displacement of the loaded condition. The vessel operates about 90% of the time in the light running condition. When testing the bulbs, the displacement was increased slightly so that the draft and trim remained constant.

When the resistance tests were run, longitudinal wave profiles were measured as the model passed a stationary wave probe. The wave probe was located 83.8 cm. from the centerline of the model and the model centerline was moved 15 cm. from the centerline of the tank in order to increase the wave record time.

The resistance results for the side bulbs show that the side bulbs failed to reduce the total resistance of the model (figure 4). Bulb 1 increased the resistance more than bulb 2 and the increase in resistance is greater at low speeds. The wave profile data, however, shows that the wave height has been reduced by the side bulb (figure 5). The wave spectrum and wave resistance were computed by the longitudinal wave cut method (Calisal, 1972) (figure 5, table 2). The wave resistance is generally reduced and yet the total resistance is increased. This indicated that another component of resistance was increased by the bulbs.

Flow visualization experiments, using tufts, found flow separation was occurring after the bulb, especially in bulb 1. Slow speed runs were used to determine the viscous dragform factor for each of the bulbs (table 3). The form factors were increased substantially by the bulbs. Increased viscous drag, it was concluded, caused the increase in resistance of the model with side bulbs.

Plasticine was added forward and aft of side bulb 2 to reduce the waterline slope in order to reduce the viscous drag. This did lower the form factor but did not lower the total

resistance significantly. A new side bulb was then designed (bulb 5) with smaller volume (figure 6). The computer program predicted about a 5.5% reduction in resistance.

Bulb 5 had about the same resistance as the original hull (figure 4). The decrease in wave resistance was equally offset by an increase in the form factor. The increase in the form factor was less than for bulbs 1 and 2 (see table 3).

It is difficult to determine why the side bulbs were not successful with the *Kynoc* hull when they had been for the UBC series. The results may have been affected by the beam to draft ratio; it was larger for the *Kynoc*, 4.06, than for the UBC series, 3.39. Michell's Integral is best suited for wall sided ships. Also, the entrance angle of the *Kynoc* is greater than the UBC series which may have cause difficulties due to the thin ship assumption of Michell's Integral. More research is required to determine when the optimization technique is valid for fishing vessel hull shapes.

3. CYLINDRICAL BULB TESTS

Three conventional cylindrical protruding bulb models were constructed (figure 7). The bulbs had a semispherical end which connect to the hull by a cylindrical section. Each of the bulbs had a different radius: bulb 3, 42 cm, bulb 4, 57 cm and bulb 6, 69 cm. The center of the semisphere was located at the forward perpendicular for all three bulbs. As with the side bulbs, the models were ballasted so that the draft and trim remained constant.

The largest bulb, bulb 6, had about a 6% reduction in resistance at 9 knots, however, at 10 knots the resistance was increased (figure 8). The smaller bulbs, bulb 3 and bulb 4, did not significantly change the resistance curve. The form factors for the cylindrical bulbs are much lower than for the side bulbs but they are higher than for the original hull. The wave resistance calculations from the wave profiles showed that bulb 6 reduced the wave resistance by 16% and that the small bulbs did not reduce the wave resistance.

From the cylindrical bulb tests, it was concluded that the large cylindrical bulb would be effective in reducing the resistance, but the fuel savings would not cover the installation cost. Further testing was therefore conducted to determine if a longer cylindrical bulb would be more effective. The model of bulb 6 was modified so that four 33 cm cylindrical extensions could be added between the semispherical end and the section that joins the bulb to the hull. This allowed the bulb to be extended forward in 33 cm increments to a total of 1.33 m. The bulbs are labelled in order of increasing length: bulb 6.2, 6.3, 6.4 and 6.5 respectively. Bulb 6.2 extended forward the same distance as the bow overhang so did not increase the length of the vessel. Bulb 6.3, 6.4 and 6.5 extended forward of the bow and thus would not ordinarily be allowed by present fishing licence regulations since they would increase the measured length.

The resistance results for the extended bulbs in the light condition show a substantial reduction in resistance as the bulb length is increased (figure 9). The resistance at 10 knots for bulb 6.5 is 20% less than the original hull. The reduction in resistance is over the

entire operating range of the vessel. For the loaded condition the changes in resistance are not as large and are greater at lower speeds. At a typical operating speed of 9 knots the resistance of bulb 6.5 is 8% lower than the original hull.

A wave profile at 10 knots shows how the bulb reduced the bow wave significantly and thus reducing the wave resistance (figure 10).

After consultations with the owner of the *Kynoc*, Bill Wilson, bulb 6.5 was selected for installation and trials. The bulb was fabricated out of aluminum by Shore Boat Builders and welded to the exterior of the hull.

4. FULL SCALE TRIALS

To further confirm the effectiveness of the bulbous bow, full scale trials were conducted before and after the installation of the bulb. The trials were conducted on a measured .5 mile course on the Fraser river (Avis & McGreer, 1989).

The vessel was powered at constant RPM back and forth between two marker buoys and the times between the marks was used to calculate the speed. The effect of the current was accounted for by averaging the against current speed and the following current speed.

The engine RPM and fuel consumption were measured with a Microfuel Systems fuel meter and the shaft torque was measured by strain gauges glued to the propeller shaft. An integrated strain gauge amplifier and FM/FM transmitter was used to get the strain gauge signals from the shaft to the data acquisition equipment.

The torque meter was calibrated while the vessel was upon ways being fitted with a bulbous bow. Torque was applied to the shaft by a 6 ft. wrench fitted to the propeller nut. A chain hoist with a 1000 lb. load cell was attached to the end of the wrench and anchored to the ways.

The trials without the bulb were done a week before the bulb was installed. The bulb installation took one week and the trials with the bulb were done the following week. No weight was moved between tests except 750 gallons of water was added to the forward tank to restore the vessel to the same trim as before the bulb.

The vessel was ballasted to the light condition tested in the model tests. The vessel had 4 inches trim by the bow more than in the model test. The owner indicated that this was the usual operating trim so the test were conducted at this trim.

The trials were conducted at six engine RPMs from 1400 to 1850. At each RPM four runs were made; two in each direction. The bulb increased the attained speeds at all RPMs. At 1600 RPM the speed increased .25 knots and at 1850 RPM the speed increased .15 knots.

In all cases tested, the fuel consumption rate was less with the bulbous bow than the original hull. At 9.5 knots, fuel consumption was reduced 13% (figure 11). The results for the shaft horsepower show good agreement with the fuel consumption values (figure 12). The power was reduced 13% at 9.5 knots.

5. CONCLUSIONS

Model testing and full scale trials on the fishing vessel *Kynoc* have proven that a bulbous bow can be an effective way to reduced fuel consumption on a medium sized fishing vessel. This project gave the rare opportunity to do both model testing and full scale testing of a fishing vessel. Although the side bulbs were not as effective as previous model tests, probably due to the smaller beam to draft ratio of *Kynoc*, further research is recommended into the feasibility of side bulb designs.

6. REFERENCES

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Hsiung, C.C., 1984. "Optimal Ship For Minimum Total Resistance", Journal of Ship Research, Vol 28, No. 3, Sept. 1984, pp. 163-172.

Dunwoody, B., Avis, J., and Molyneux, D., 1989. "Reducing Added Resistance of Boats Using a Bulbous Bow", International Fisheries Energy Optimization Working Group Proceedings.

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Calisal, S.M., 1972. "Effect of Wake on Wave Resistance", Journal of Ship Research, SNAME, June 1972, pp. 93-111.

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Table 1

Constraints Used in the Design of Bulb 1

hull offsets less than 1/2 beam

waterline slope less than 34 degrees

waterline area fixed

3.5% increase in volume

offset for station 9.5 less than .4 times 1/2 beam

Table 2

Form Factors Results

Draft	Kynoc	Bulb 1	Bulb 2	Bulb 3	Bulb 4	Bulb 5	Bulb 6
1	1.16	2.25	1.83	1.43	1.22	1.57	1.51
2	1.72	2.71	1.96	1.82	1.49	2.07	

Table 3

Comparison of Wave Resistance Coefficents for Kynoc

Draft 1	Kynoc	Bulb 1	%	Bulb 2	%	Bulb 3	%	Bulb 4	%	Bulb 6	%	Bulb 6.1	%
8 Knots	0.00161	0.00118	-26.7	0.00124	-23.0	0.00166	3.1	0.00157	-2.5	0.00134	-16.8	0.0011	-31.7
10 Knots	0.00172	0.00168	-2.3	0.00188	9.3	0.00187	8.7	0.00273	58.7	0.00144	-16.3	0.00104	-39.5
Draft 2													
8 Knots	0.00126	0.00111	-11.9	0.00103	-18.3	0.00097	-23.0	0.00099	-21.4			0.00133	5.6
10 Knots	0.00159	0.00166	4.4	0.00149	-6.3	0.00148	-6.9	0.00176	10.7			0.00216	35.8

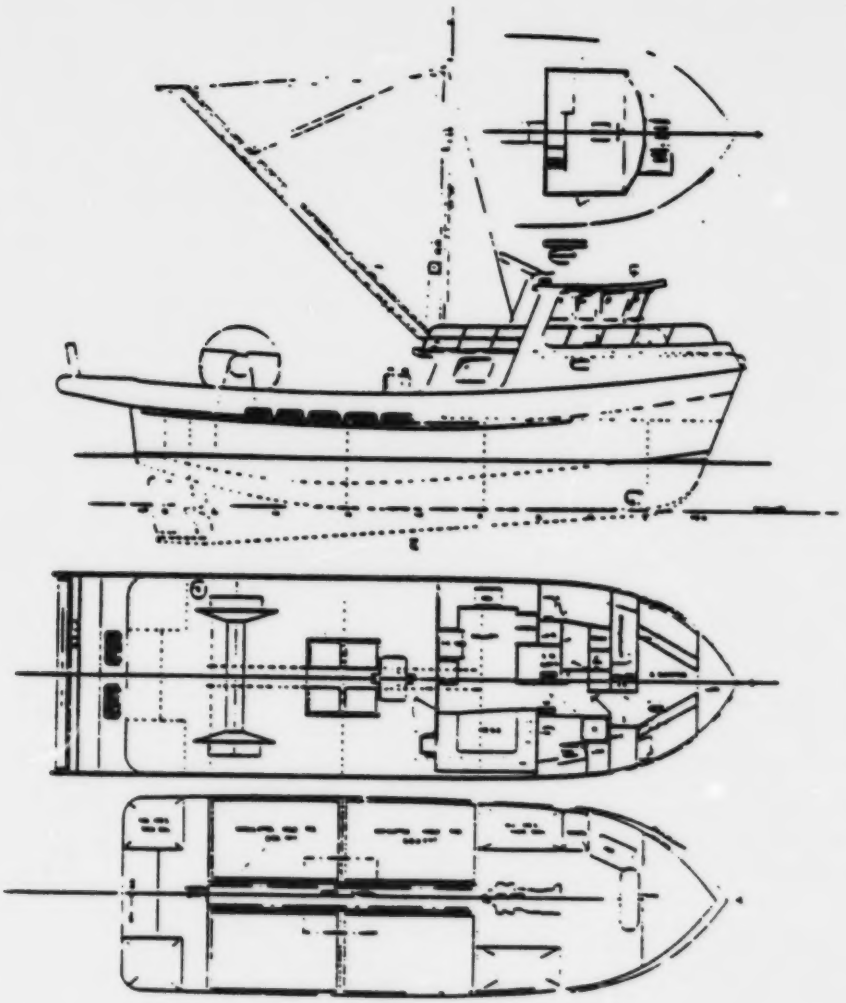


Figure 1 General Arrangement of 'Kynoc'

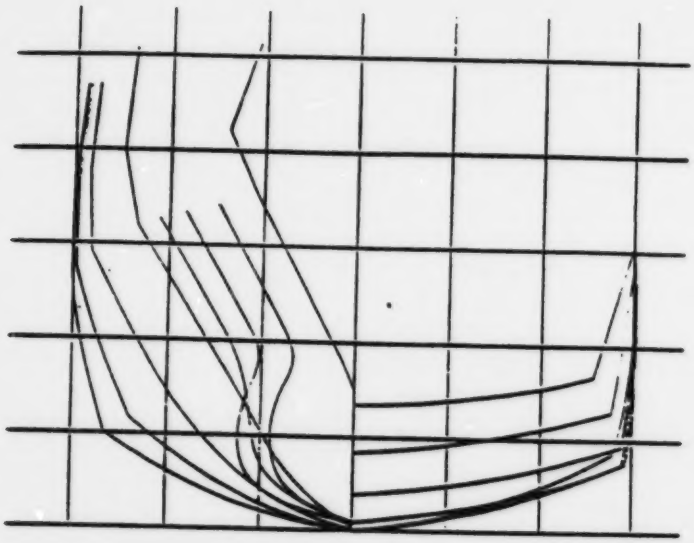


Figure 2 Side Bulb 1

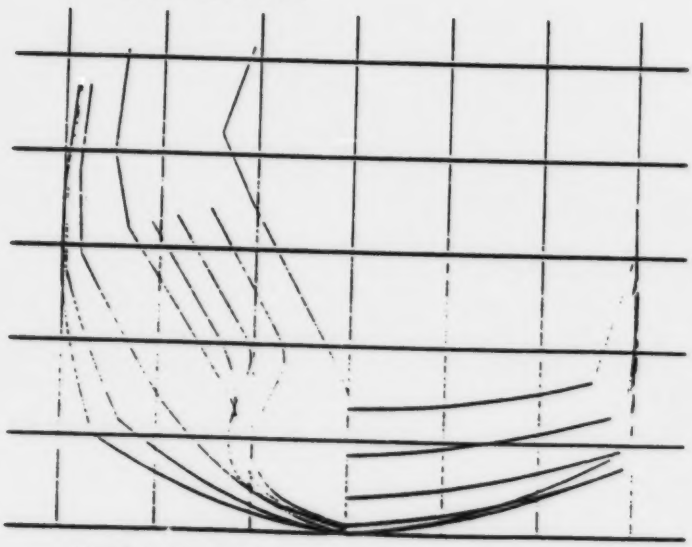


Figure 3 Side Bulb 2

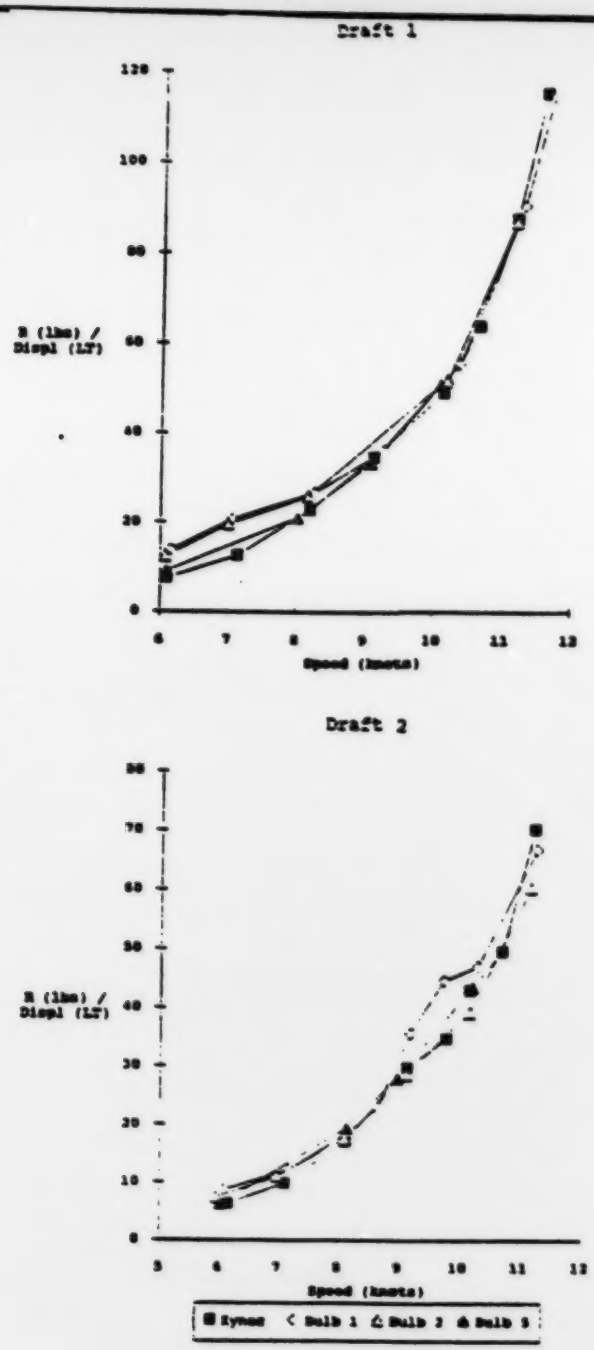
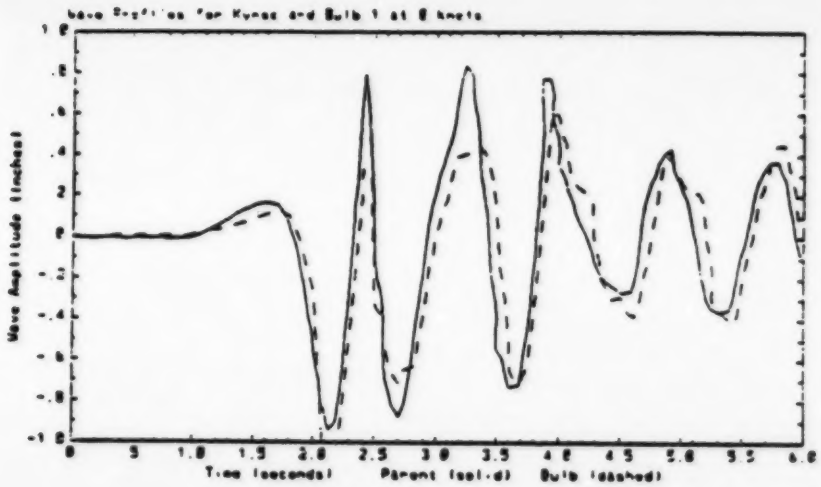


Figure 4 Resistance versus Speed for Side Bulbs



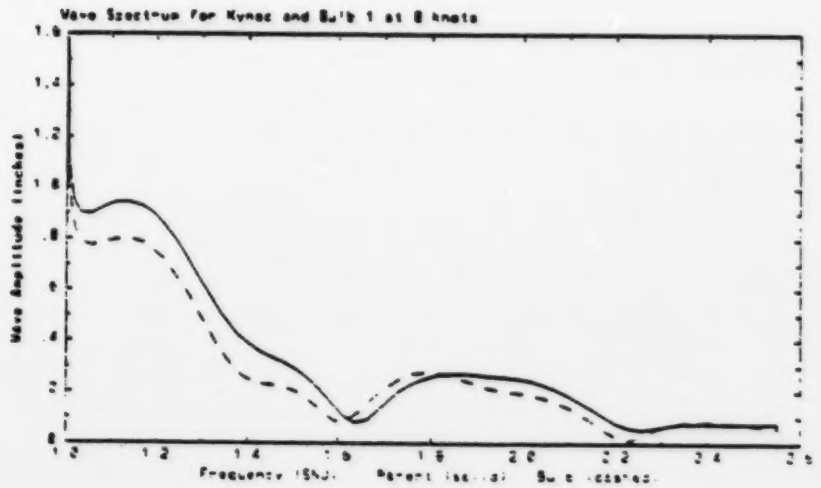


Figure 5 Wave Profile of Bulb 1 at 8 knots

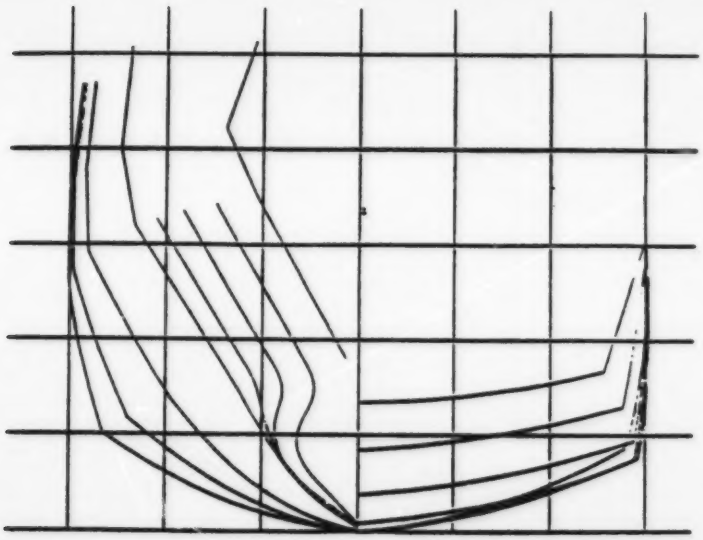


Figure 6 Side Bulb 5

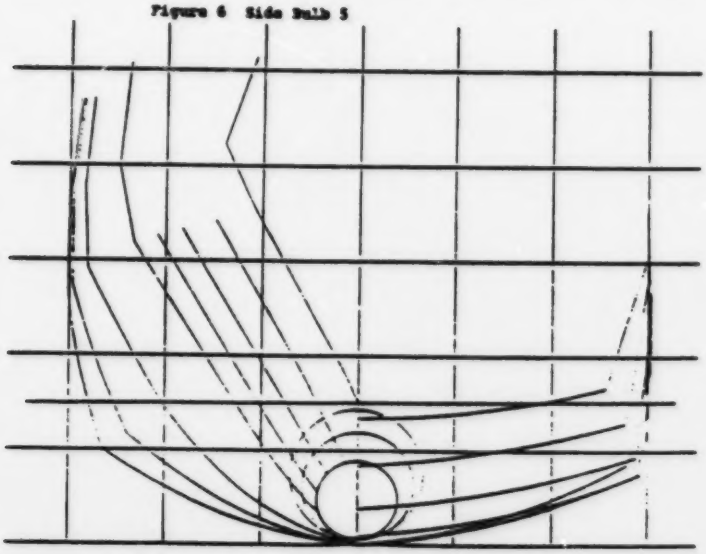


Figure 7 Cylindrical Bulbs 3, 4, 6

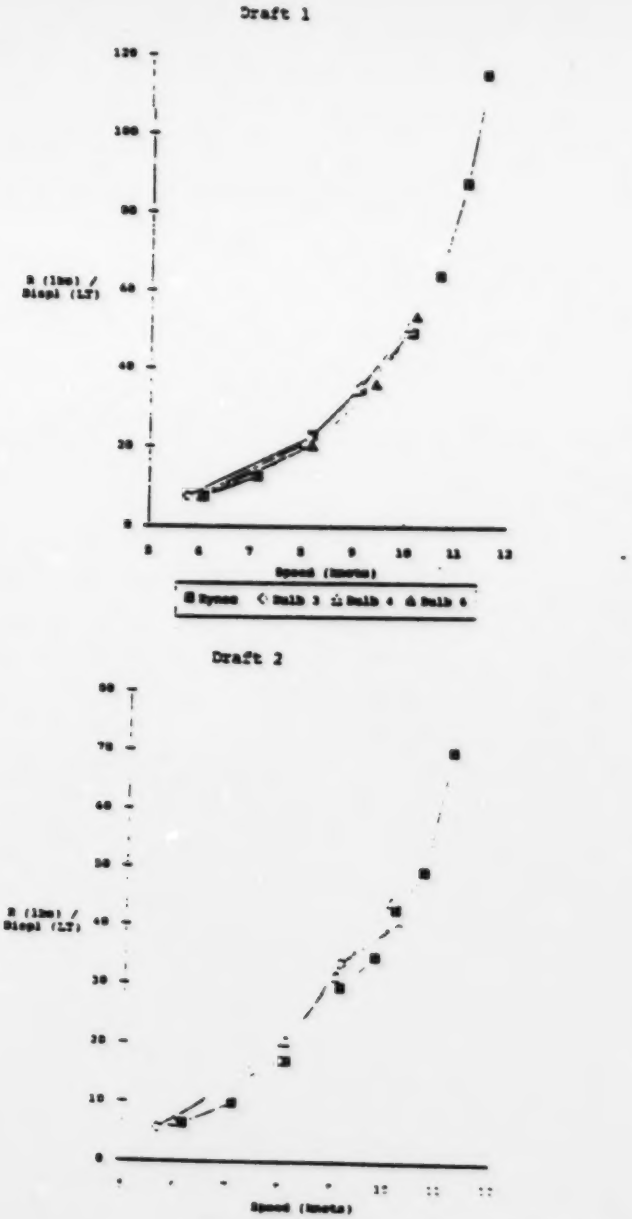


Figure 8 Resistance of Cylindrical Bulbs

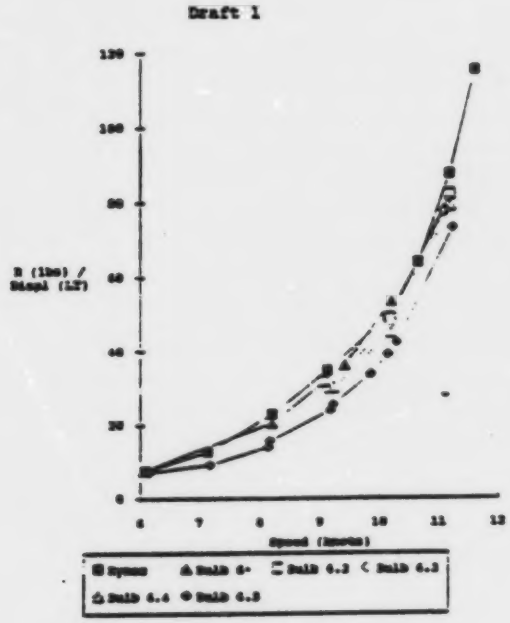


Figure 9 Resistance of Extended Bulb 6

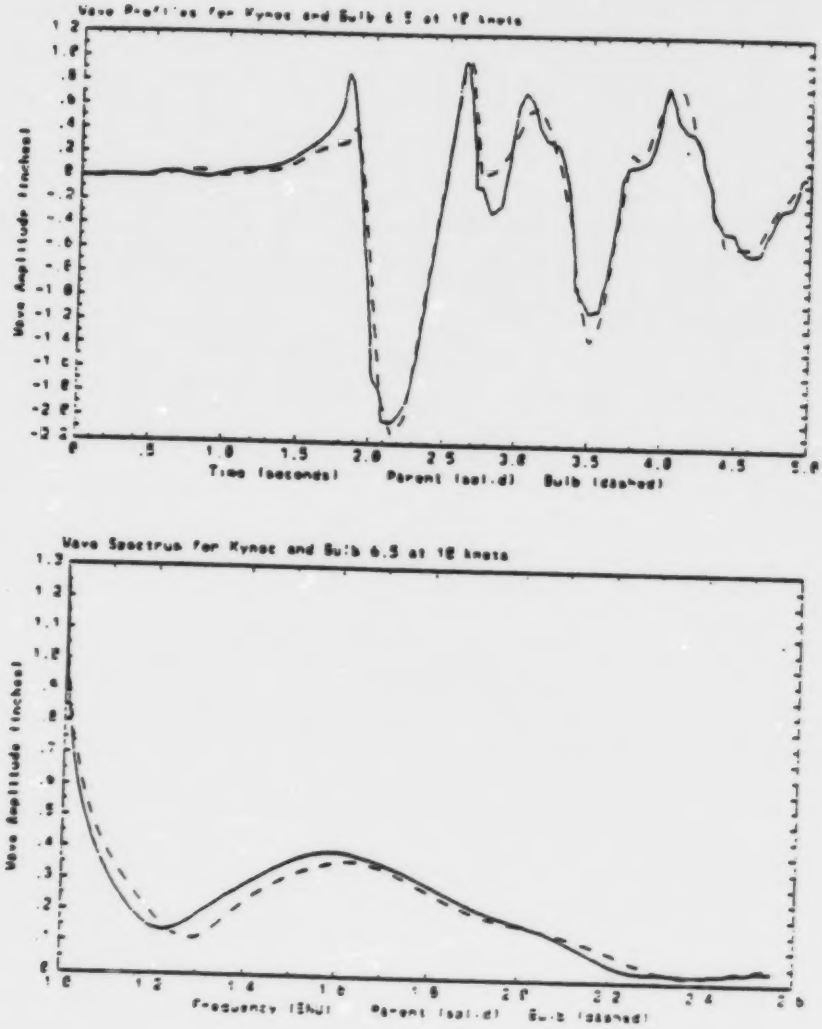

Wave Amplitude (inches)
Time (seconds)
Parent (solid) Bulb (dashed)
Wave Spectrum for Kynoc and Bulb 6.5 at 10 knots
Wave Amplitude (inches)
Frequency (Hz)
Parent (solid) Bulb (dashed)

Figure 10 Wave Profile of Bulb 6.5 at 10 knots

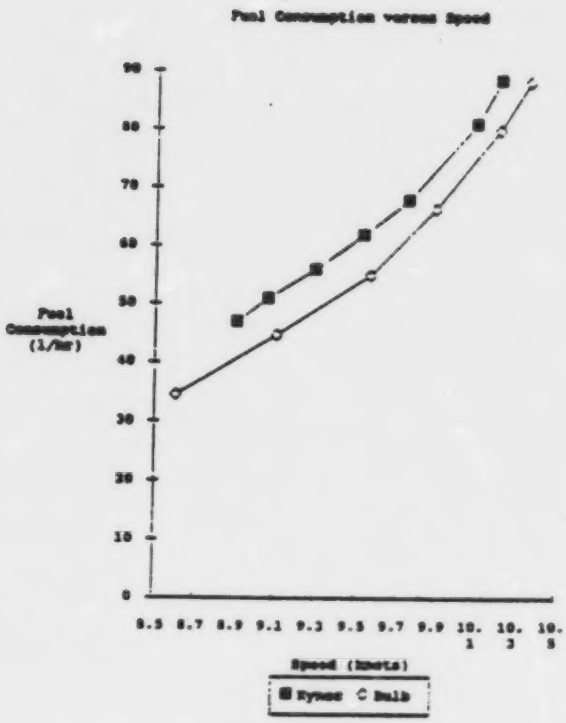


Figure 11 Fuel Consumption versus Speed from Sea Trials

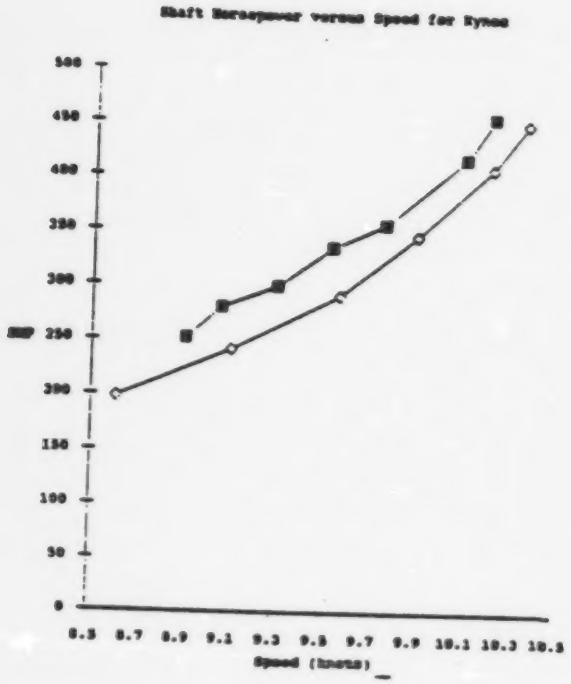


Figure 12 Shaft Horsepower versus Speed from Sea Trials

APPENDIX C

REDUCING ADDED RESISTANCE OF FISHING BOATS USING A BULBOUS BOW

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B. DUNWOODY - Assistant Professor, University of British Columbia
D. MOLYNEUX - Research Officer, National Research Council

ABSTRACT

The results of regular head wave towing tank experiments for a 1:8 scale model of the drum seiner *Kynoc* are presented for both the bare hull and the hull fitted with a large cylindrical bulbous bow. These results show that the bulbous bow is very effective in reducing the heave and pitch motion amplitudes and added resistance, with heave being reduced by 10%, pitch by 25% and added resistance by as much as 38%.

Strip theory heave and pitch motion calculations were carried out on the vessel with and without the bulb. Added resistance was then predicted using the modified Joosen method and the strip theory motion results. There is good agreement with experiment in predicting the decrease in added resistance that can be expected from the addition of the bulbous bow. The Joosen method, in conjunction with strip theory, could be a very useful preliminary design tool for naval architects to aid in the design of energy efficient bulbous bows for fishing vessels.

It is concluded that the bulbous bow is a very effective method of reducing added resistance in a seaway of a fishing boat and therefore could lead to significant energy savings.

1. INTRODUCTION

The purpose of this research was to investigate the effect of a large cylindrical bulbous bow on the added resistance of a fishing vessel in a seaway.

A bulbous bow was designed for the drum seiner *Kynoc* for the conventional purpose of reducing the calm water resistance of the hull and hence improve energy efficiency, (the subject of another paper for this conference). In a recent article by Wolff (1989) it was suggested that a bulbous bow could also reduce a vessel's pitch amplitude in a seaway. As vessel motion is directly related to added resistance, it was hoped that a bulbous bow might also reduce added resistance of a vessel in waves and lead to even greater energy savings.

To investigate this thought, a series of scale model tests were conducted in regular head waves for the original *Kynoc* hull and for the hull fitted with a bulbous bow in order to obtain the vessels motion and added resistance response characteristics. In addition, linear strip theory and added resistance calculations were carried out to determine if the effect of the bulbous bow could be predicted through theoretical means.

2. BACKGROUND

2.1 Phenomenon of Added Resistance

Added resistance is the resistance over and above the calm water resistance that a ship experiences under the influence of wind and waves. Thus a ship operating at a certain speed in wind and waves will usually require more power than the same ship operating at the same speed in perfectly calm waters.

2.2 Causes of Added Resistance

The added resistance of a ship is caused by the following factors (Avis, 1989; Strom-Tejsen, 1973).

1. Wave reflection or diffraction of the incident wave system by the ship.
2. The motion of the ship (rigid body motions). The vertical motions heaving and pitching, have the largest effect.
3. Sideslip or drift angle of the ship due to the wind or wave system side force exerted on the ship.
4. Windage on the superstructure and hull.
5. Motion of the control surfaces. Rudder movements will influence the motion of the ship.
6. Change in propeller efficiency because the propeller is operating in a fluctuating flow due to the motion of the ship.

This investigation deals only with components (1) and (2) - the motions being restricted to heave and pitch in head seas. Many previous researches have identified items (1) and (2) as the largest contributing factors in the head sea case and the head sea case has been shown to produce maximum added resistance (Bhattacharyya, 1978; Strom-Tejsen, 1973).

2.3 Research on Ships

In recent years several experimental and analytical methods have been developed for the prediction of motions and added resistance of regular cargo ship hulls (Strom-Tejsen, 1973; Wilson, 1985). These have resulted in the following findings:

- Principle of linear superposition is valid for motion and added resistance tests (Gerritsma, 1962).
- Ship motions are proportional to wave amplitude (Strom-Tejsen, 1967).

- Added resistance is proportional to wave amplitude squared (Strom-Tejsen, 1973).
- Scaling of added resistance can be carried out under Froude's Law (Bhattacharyya, 1978).
- Strip theory of computing added mass and damping is valid (Wilson, 1985).

These results have been extended to include fishing boat hull forms; however many fishing vessel hull forms tend to have very low L/B and L/D ratios compared to cargo ships. This can cause deviations from the assumptions which are made in strip theory calculations of motions and added resistance.

3. EXPERIMENTAL PROGRAM

To experimentally determine the added resistance response characteristics in waves, a 1/8 scale model of the *Kynoc* was built with a removable cylindrical bulbous bow. Model tests were carried out in the deep water towing basin at the B.C. Research Ocean Engineering Centre.

3.1 Test Program

The test program consisted of regular sinusoidal head wave tests. All wave tests were carried out at a constant model speed corresponding to nine knots full scale and at a constant wave hight corresponding to three feet full scale. The constant velocity method of wave testing was used. Using this method the model is free to heave and pitch but restricted in surge, sway, yaw and roll. Wave tests were completed for the original hull and the hull with bulbous bow for at least ten non-dimensional encounter frequencies between μe=2.0 and μe=4.5 where

$$\mu\theta = \omega\theta^* \sqrt{(L/g)}$$

The quantities measured during the test were pitch angle, heave displacement, resistance and speed. Wave height was also measured using an electro-mechanical wave probe near the midpoint of the tank. Calm water resistance tests were also conducted in order to provide a baseline for the calculation of added resistance.

3.2 Observations And Results

The data from the tests was reduced and all quantities non-dimensionalized.

Figure 1 shows the experimental heave response for the original *Kynoc* hull and for the hull fitted with bulbous bow. Note that at the lower frequencies, the bulb actually increases the heave response. However, at the higher frequencies, the bulb decreases the heave response by approximately 10%.

The pitch response is shown in Figure 2. The pitch amplitude is reduced over the entire frequency spectrum when the bulb is fitted. At resonance and above, the reduction due to the bulb is as much as 24%. It appears that the bulb is in fact very effective in reducing the pitch amplitude response as suggested in Wolff (1989).

Figure 3 shows the non-dimensionalized added resistance spectrum for the *Kynoc* with and without bulb. At frequencies above μe=3.0, the bulb causes a dramatic decrease in the added resistance. In fact the reduction in added resistance at resonance is up to 38%. This is a significant savings and appears to show that the bulbous bow could increase energy efficiency of fishing vessels in waves.

4. THEORETICAL MODEL

With these encouraging experimental results, it was decided to carry out a mathematical model investigation, to determine if existing ship motion and added resistance strip theory could be used to help predict the effect of the bulbous bow.

Motions were calculated using conventional linear strip theory presented by Salvesen, Tuck and Fattinsen and used in the Frank Close-Fit Computer Program (Frank, 1970).

The coupled equations of motion for heave and pitch are

$$(M+A_{33})\ddot{z} + B_{33}\dot{z} + C_{33}z + A_{35}\ddot{\theta} + B_{35}\dot{\theta} + C_{35}\theta = F_{3\theta}e^{i\omega t}$$

$$A_{53}\ddot{z} + B_{53}\dot{z} + C_{53}z + (I + A_{55})\ddot{\theta} + B_{55}\dot{\theta} + C_{55}\theta = F_{5\theta}e^{i\omega t}$$

where A_{ij}, B_{ij}, etc. are the frequency and speed dependent added mass and damping coefficients and C_{ij} are the hydrostatic restoring coefficients and are assumed to be constant.

The predicted added resistance was calculated from the results of the strip theory motion calculations and using the modified Joosen method (Strom-Tejsen, 1973). This theory is based on a slender body approximation for the drift forces and is valid for short waves. The wave diffraction effect is assumed to be negligible under this theory; therefore the theory also breaks down for very short waves where the diffraction effects become dominant. The added resistance is determined through a knowledge of the ship's frequency dependent damping coefficients as well as information on the heaving and pitching motion amplitudes and phases.

The final form of the modified Joosen equation is

$$\sigma_{aw} = E_1 + E_2 + E_3$$

where

$$E_1 = C_0 \overline{B_{33}} (z_a/\zeta_a)^2$$

$$E_2 = C_0 (2\pi L/\lambda)^2 \overline{B_{55}} (\theta_a/k\zeta_a)^2$$

$$E_3 = -2\, C_0 (2\pi L/\lambda) \overline{B_{35}} (z_a/\zeta_a) (\theta_a/k\zeta_a) \cos\varepsilon$$

$$C_0 = \frac{1}{16} \frac{L^2}{B^2} \frac{(\omega_e^* \sqrt{(L/g)})^3 \nabla}{L^3}$$

$$\varepsilon = |\varepsilon_z - \varepsilon_\theta|$$

The damping coefficients in the above equations are given by

$$B_{33} = (1/\omega_e \nabla)(g/L)^{1/2} \int b_{33}(\xi)\, d\xi$$

$$B_{35} = (1/\omega_e \nabla)(g/L)^{1/2} \int (\xi-\xi_o)\, b_{33}(\xi)\, d\xi$$

$$B_{55} = (1/\omega_e \nabla)(g/L)^{1/2} \int (\xi-\xi_o)^2\, b_{33}(\xi)\, d\xi$$

The predicted added resistance is calculated using the previously calculated damping coefficients and motion responses from the Frank Program.

The results for the added resistance calculations are shown in Figure 4. Note that the bulb is predicted to lower the added resistance by as much as 37% at resonance and above.

5. COMPARISON OF THEORY AND EXPERIMENT

Figure 5 shows a comparison between theory and experimental pitch response of the *Kynoc* with and without the bulb. The theory tends to overpredict the pitch response for the original hull while it underpredicts the response of the hull with bulb fitted. The result is that the reduction in pitch due to the bulb is overpredicted by theory. At resonance and above the bulb is predicted to reduce pitch by up to 40%. This compares to the 24% reduction observed in the experiments. Though the theory does overpredict the benefit of the bulb, it is a useful indicator of the effect of the bulb on the pitch motion amplitude.

A comparison of the heave response with and without the bulb appears in Figure 6. The theory tends to overpredict the heave amplitude in the resonant range. However the relative difference in response between the bulb and no-bulb case is predicted well by theory.

A comparison of experimental and theoretical added resistance spectrums with and without the bulb is shown in Figure 7. The Joosen theory tends to underpredict the added resistance above frequencies of ω_e=2.75. However, the theory does indicate a relative decrease in added resistance due to the bulb that is similar to that determined by experiment.

6. CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that the addition of a large cylindrical bulbous bow to an existing typical fishing vessel hull can significantly reduce the pitch motion and the added resistance of the vessel in waves. This reduction in added resistance due to the bulbous bow combined with the conventional reduction in calm water could result in significant energy savings in the operation of the fishing vessel.

The Joosen method of calculating added resistance combined with strip theory heave and pitch motion prediction techniques could be a valuable tool for naval architects to aid in the design of energy efficient bulbous bows for fishing vessels.

Full scale observations by the owner of the *Kynoc* indicate that the bulbous bow has been effective in reducing pitch motions of the vessel in a seaway as well as allowing the modified vessel to maintain higher speeds in waves as compared to the original hull.

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NOMENCLATURE

A_{ij}	=	Added mass coefficients
B	=	Beam of ship
B_{ij}	=	Damping coefficients
C_{ij}	=	Restoring coefficients
F_3	=	Heave exciting force
F_5	=	Pitch exciting movement
I_5	=	Moment of inertia for pitch
L	=	Length of ship
M_{jk}	=	Mass coefficients of ship
V	=	Forward velocity of ship
$b(\xi)$	=	Sectional beam
b_{ij}	=	Two dimensional sectional damping coefficient
g	=	Gravitational acceleration
k	=	Wave number
z	=	Heave displacement (positive up)
z_a	=	Heave amplitude
E_z	=	Heave phase angle
E	=	Pitch phase angle
ξ_a	=	Wave amplitude
θ	=	Pitch angle (positive bow down)
θ_a	=	Pitch amplitude

Figure 1
Results of Experiments in Regular Waves
Non-dimensional Heave Response

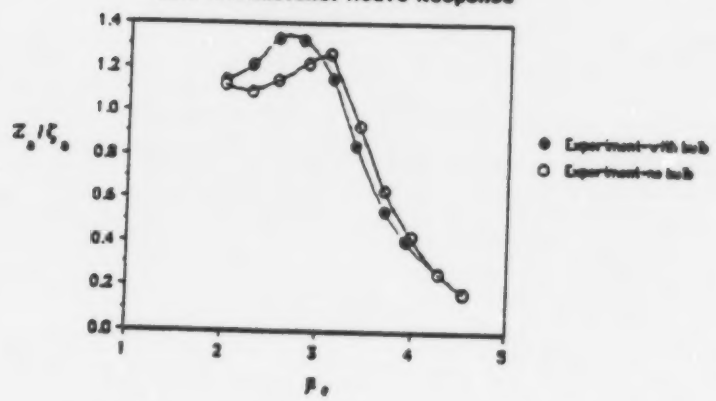


Figure 2
Results of Experiments in Regular Waves
Non-dimensional Pitch Response

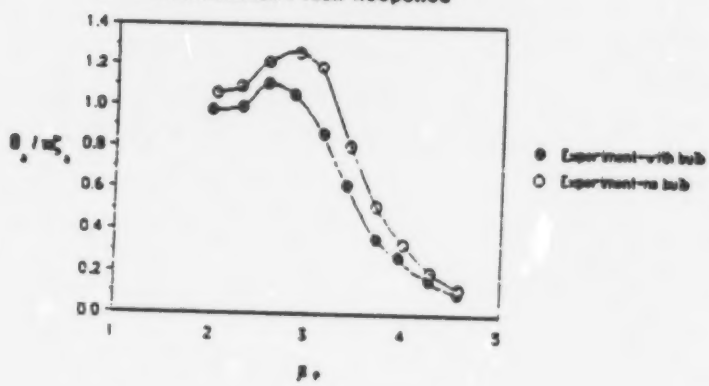


Figure 3
Results of Experiments in Regular Waves
Added Resistance

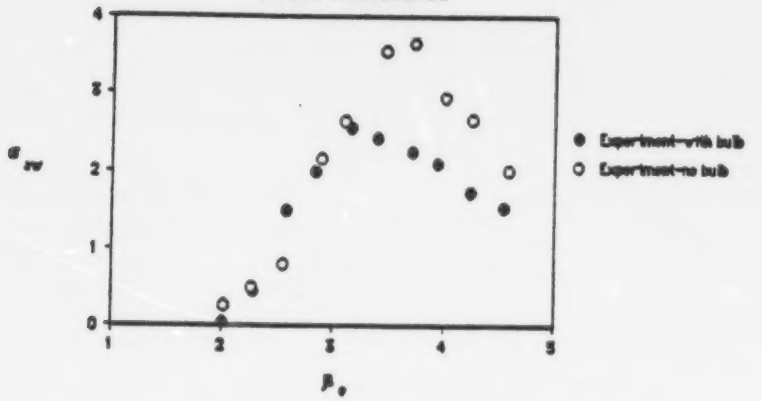


Figure 4
Prediction of Added Resistance in
Regular Waves

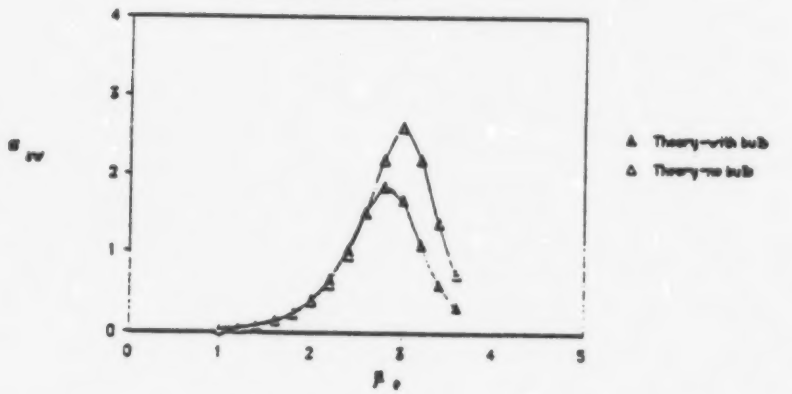


Figure 5
Comparison of Measured and Predicted
Non-dimensional Pitch Response

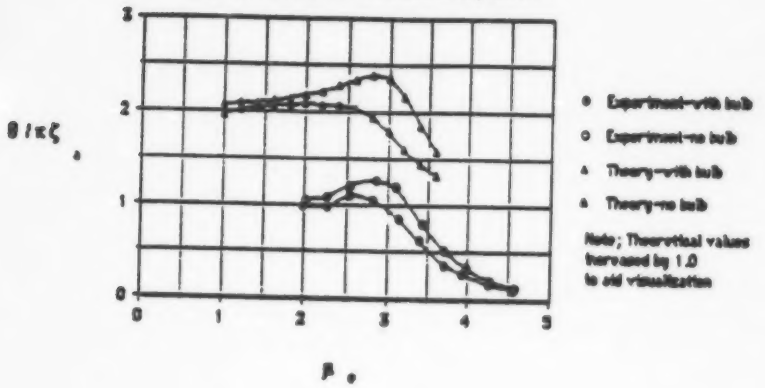
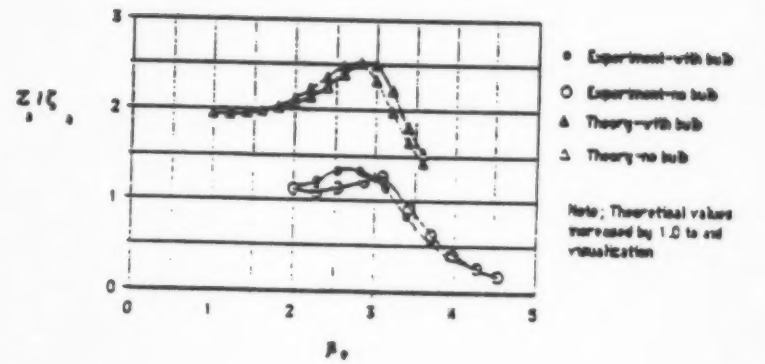


Figure 6
Comparison of Measured and Predicted
Non-dimensional Heave Response



APPENDIX D

DESIGN AND TESTING OF BEAVERTAIL NETGUARDS ON WEST COAST DRUM SEINERS

DON SCHROEDER, B.SC., JOHN BRANDLMAYR LTD. and
GEORGE RODDAN, B.SC., B.C. RESEARCH

ABSTRACT

The paper covers a brief history and design philosophy of "beavertail" netguards. An improved wing-type beavertail design is introduced and is the subject of model self-propulsion tests comparing them to the more conventional pipe beavertails. Results of the model tests indicate a reduction in delivered horsepower of up to 23% at 10 knots for the wing-type beavertail over the old design. Some full scale test results are presented which confirm the model predictions.

1. INTRODUCTION

Nets are used in fisheries all over the world. Where nets are used in conjunction with sail power or muscle power, there are few problems with the fishing vessel fouling the net. For all powered vessels, however, the propeller is always a concern. This concern varies from minor, in the case of trawlers where the net spends most of its time far aft of the propellers, to extreme, in the case of the purse seine fisheries of the West Coast of North America (see Figure 1 for a typical seiner). Here the net is in close proximity to the propeller, and net fouled propellers are a common problem. West Coast fisherman have solved this problem with a paddle shaped pipe structure attached to the rudder shoe and keel, directly beneath the propeller (see Figure 2). These net guards, commonly known as "beavertails" have received very little attention from Naval Architects or other technically qualified people. Typically they are designed by the builders and the fishermen. They are effective in reducing down-time due to fouled propellers and torn nets, but detract greatly from operating efficiency. The purpose of this paper is to discuss the results of a radical change in the design of these "beavertail" net guards. Instead of the typical, open pipe structure a closed plated structure has been designed with a hydrofoil wing section (see Figure 3). This "winged-beavertail" was intended to 1) reduce the significant amount of drag generated by the open pipe structure, 2) reduce the turbulence in the vicinity of the propeller which is induced by the pipe beavertail and 3) accelerate the water through the propeller much in the same manner as a nozzle, reducing the effective wake and hopefully increasing propulsive efficiency.

2. HISTORY AND FIRST TRIALS

Over the years, many seine boats, previously without the pipe beavertail, have had them fitted. From the resulting loss in vessel speed, it has been clear to the fishermen that the pipe beavertail is a significant cause of vessel inefficiency. A number of attempts have been made to reduce the resistance of the pipe beavertail by covering it with plating. Most of these plated beavertails have had structural problems, although a few have apparently been successful. As with fishermen everywhere, what is important is catching the fish, not

precisely how fast the boat is or in precisely what condition so naturally hard data on these experiments is very difficult to locate. Results are not published and recollections of trials are vague and anecdotal.

One of us (Mr. Schroeder) has had the opportunity to work closely with the same builder for a number of years. During that time 20 seiners have been designed and built. Each of these vessels has been trialed in a careful and consistent manner so that a reliable body of data is available for study. Of these vessels 13 were built with the pipe beavertail and seven with the new "winged beavertail". Three of the vessels were nearly identical to vessels built with pipe beavertails allowing a useful comparison of trial results. In addition, the second vessel built in the present series, *Kynoc*, was first model tested, then the full scale vessel was retrofitted with a "winged beavertail" and bulbous bow, and carefully trialed by the University of British Columbia's Department of Mechanical Engineering.

The first vessel to be fitted with the "winged beavertail" was the 15.3 meter purse seiner *Hogan Isle*, delivered in the spring of 1988. Since the *Hogan Isle* was nearly identical to the *Ocean Mirage* which was delivered a year earlier with a conventional pipe beavertail, a useful comparison was possible.

The resulting analysis of the trial results of both vessels indicated that the increase in running efficiency due to the "winged beavertail" was 18.8%. (1) Four more 15.5 meter purse seiners of identical underwater profile and similar installed horsepower have been built and delivered. Of these, four boats, the *Western Lady* and the *Western Rover* were fitted with "winged beavertails" while the *Ocean Ripple* and *Ocean Summer* had conventional pipe beavertails. A comparison of the trials results corroborated the previous results with an estimated increase in efficiency due to the "winged beavertail" of 18.2%. (2) A reduction of vibration and noise in the stern area, particularly during the crash stops, was also noted.

3. THE "KYNOC" PROJECT AND THE MODEL TESTING

Because of the success of the *Hogan Isle* it was decided to include a study of the "winged beavertail" in a demonstration project sponsored and partially funded by the Department of Energy, Mines and Resources, Canada. This project was to include the model testing and retrofitting of an existing Canadian purse seiner with both a bulbous bow and the "winged beavertail", (3,4,5). The following describes the results of the self-propulsion tests performed to evaluate the two different types of beavertails.

4. MODEL SELF-PROPULSION TESTS

4.1 General Test Program

Pacific Fisheries Research and Development Ltd. contracted the Ocean Engineering Centre of B.C. Research to perform model tests on a 60-foot seiner. Funding for this program was

provided through the Dept. of Energy, Mines and Resources (EMR). The Vessel examined under this program was the 60-ft. (18.29-meter) seiner *Kynoc* which was designed by John Brandlmayr Ltd. and built by Shore Boats Ltd. in 1987. The *Kynoc* is owned and operated by Mr. Bill Wilson.

The purpose of the test program was to determine the effects on the performance and seakeeping ability of the *Kynoc* which would result from various retrofitted appendages. The first task was to optimize for minimum resistance a bulbous bow design developed by the Mechanical Engineering Department of U.B.C. The effects of the optimized bulb on the nominal wake and seakeeping behaviour of the design were also examined. Next, the relative effects on running efficiency of two types of "beavertails" (propeller guards) were investigated. In this case a standard pipe net guard was compared to an innovative wing-type net guard designed by John Brandlmayr Ltd. The methodology and results of the self-propulsion tests are described below.

4.2 Model

A wooden model was built to a scale of 1:8 from a set of lines provided by John Brandlmayr Ltd. The general arrangement is shown in Figure 1. To facilitate quick changing of the various bulb configurations the model was built with a removable bow section. The model was also fitted with a removable rudder.

To allow self-propulsion tests to be performed, the model was fitted with a propulsion motor, stern tube, shaft, Kempf and Remmers shaft dynamometer and a 7-inch diameter four blade brass propeller (P/D = 0.60, Ae/Ao= 0.40). The propeller was constructed by mounting blades provided by IMD (Institute of Marine Dynamics, NRC, St. John's, Nfld.) to a hub machined at B.C. Research, (see Figures 4 and 5).

Two different types of beavertails were constructed and attached to the model in place of the rudder-shoe (see Figures 2 and 3).

In preparation for testing, the model was marked with a grid of stations and waterlines. Brass studs, 0.125 inches in diameter by 0.100 inches long were installed at one inch centres on station 1 to stimulate turbulent flow.

The model test configurations were as follows:

TEST CONFIGURATION	DISPLACEMENT (L.T. SW)	COMMENTS
D-1a	86.5	Bulb 6-5, pipe beavertail
D-2b	86.5	Bulb 6-5, wing beavertail

4.3 Self-Propulsion Test Procedures

All speeds, displacements and dimensions given in the balance of this paper are full-scale equivalents of model values unless otherwise stated.

The model was towed free to pitch and heave, but was fixed in surge yaw and roll. The towing bracket was mounted in the same position as for the resistance tests, i.e. at station 5.25 with pivot at a vertical position corresponding to 11.83 ft above the baseline.

The self-propulsion tests were run for each configuration at two carriage speeds corresponding to 9 and 10 knots. Speed, resistance, propeller thrust, torque and rpm were recorded for each run. The propeller revolutions were set on successive runs to cover a range of thrust above and below that required for self-propulsion of the model. The resistance dynamometer is used to supply any deficit towing force or resist any excess thrust so as to maintain the model at constant speed. By plotting these resistance values to a base of propeller rpm, the model self-propulsion point can be determined accurately.

4.4 Self-Propulsion Test Results

Figures 6 and 9 present the results of the self-propulsion tests. To extrapolate the results, a standard method recommended by the Propulsion Committee at the 1957 ITTC conference was employed. The ship self-propulsion point is determined in the plots by correcting for the reduced loading of the ship's propeller (due to frictional resistance scale effects) using the ITTC 1957 correlation line, and adding in a roughness allowance of 0.0004. See Tables 1 and 2 for friction corrected self-propulsion points.

To determine the reduction in propeller loading (in pounds):

$$\text{Delta} = 0.5(\text{rho})\ V^2 A\ (Cfm - Cfs - Ca) \qquad (1)$$

where,

rho = density of water, (1.94 lb-sec^2/ft^4)
V = model speed (ft/sec)
A = model wetted area (ft^2)
Cfm = frictional resistance coefficient for model, ITTC 1957
Cfs = frictional resistance coefficient for ship, ITTC 1957
Ca = roughness allowance, (0.0004 typ.)

Once this correction is applied, the ship self-propulsion point is determined. From the corresponding curves of thrust and torque, together with the open water curves for the propeller (see Figure 11), the various propulsion factors can then be found. These factors are determined by applying the following equations to the experimental data:

$$\text{Thrust coeff., } Kt = T/(\text{rho} n^2 D^4) \qquad (2)$$

Torque coeff., $Kq = Q/(rho n^2 D^5)$ (3)

From open water data determine:

advance ratio, $J = Va/(n \cdot D)$ (thrust identity)
open water efficiency = ηo

- next determine efficiencies:

efficiency behind hull, $\eta b = TVa/(2 \cdot \pi \cdot n \cdot Q)$ (4)

relative rotative eff., $\eta r = \eta b/\eta o$ (5)

thrust deduction, $t = 1-(Rt/T)$ (6)

effective wake, $wt = (V-Va)/V$ (7)

hull efficiency, $\eta h = (1-t)/(1-wt)$ (8)

quasi-propulsive eff., $\eta d = (\eta h \cdot \eta r \cdot \eta o)$ (9)

Definitions:

D = model propeller diameter, (ft.)
T = model propeller thrust, (lb.)
Q = model torque (ft.-lb), (note: model torque is plotted in in.-lb)
n = model propeller rotation rate (revolutions/sec)
rho = density of fresh water (1.94 lb-sec^2/ft^4)
Va = speed of flow at model prop, (ft/sec)
Rt = total drag of hull, at speed V, without propeller (lb.)

See Tables 3 and 4 for the full scale self-propulsion points determined using the open water propeller data. For a more detailed description of self-propulsion tests see reference 6.

Tables 5 and 6 present the full scale self-propulsion data in terms of efficiencies. Note that higher relative rotative efficiency (at 9 knots) of the wing-type beavertail results in an increased overall efficiency, d. This indicates that the wing-type design promotes better flow conditions for the propeller. The larger thrust deduction and wake factor for the wing beaver tail indicates there may be room for some improvement in terms of the form and angular placement of this appendage. (The winged beavertail actually retrofitted to the *Kynoc* differed in two respects from the one model tested. The downward angle was increased and the wing section was changed. The intention was to reduce the wake from the high values noted during model testing. The results of the full scale trials indicate some success. See Tables 7 & 8.) Figure 12 shows a graph of DHP vs Speed for the pipe and wing beavertails. This graph indicates that a reduction in required power of 23% may be attained at 10 knots for the wing beavertail.

5. CONCLUSIONS

The model test program has shown that it is possible to achieve significant improvements in the hydrodynamic efficiency of a drum seiner through the use of retrofitted appendages.

The model tests comparing the effects on propulsion of a standard pipe beavertail, as opposed to a new and innovative wing beavertail, have shown that the wing beavertail results in a powering reduction of 23% at 10 kt. and 24% at 9 kt.

These model predictions are born out by the results of the full scale trials of the *Kynoc* tested at the same corresponding displacement condition. Figures 12 and 13 indicate that for the bulb and wing condition the full scale results follow quite closely the model predictions.

While this test program has concentrated on the *Kynoc*, similar results should be attainable with vessels of like form. It should be cautioned though, that the design of the bulbous bow and beavertail is very sensitive to small changes in geometry. This study has made it clear that analytical techniques alone are at present unable to produce an optimal design. It is therefore recommended that model tests always be performed as part of the design process.

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TABLE 1
FRICTION CORRECTED
MODEL SELF-PROPULSION POINTS

CONFIGURATION D-1A PIPE BEAVER-TAIL

SPEED (KT)	R_t (LB)	T_i (LB)	DELTA (LB)	CORRECTED MODEL (CA=0.0004) RPM	THRUST (LB)	TORQUE (IN-LB)
9	7.51	8.90	0.70	1084	8.05	7.27
10	10.96	13.75	0.83	1315	12.90	10.95

TABLE 2
FRICTION CORRECTED
MODEL SELF-PROPULSION POINTS

CONFIGURATION D-1B WING BEAVER-TAIL

SPEED (KT)	R_t (LB)	T_i (LB)	DELTA (LB)	CORRECTED MODEL (CA=0.0004) RPM	THRUST (LB)	TORQUE (IN-LB)
9	5.93	7.40	0.70	1025	6.60	5.81
10	9.33	11.90	0.83	1234	10.82	9.27

R_t = Hull Drag without Propeller

T_i = Thrust of Model Propeller at Speed

Delta = Frictional Correction

TABLE 3
FULL SCALE SELF-PROPULSION POINTS
USING OPEN WATER PROPELLER DATA

CONFIGURATION D-1A PIPE BEAVER-TAIL

SPEED (KT)	PROP RPM	K_t	K_q	J	η_o	ω	t	P_D (Full Scale HP)
9	383	0.110	0.0142	0.424	0.544	0.173	0.156	185
10	464	0.120	0.0149	0.406	0.525	0.136	0.202	347

TABLE 4
FULL SCALE SELF-PROPULSION POINTS
USING OPEN WATER PROPELLER DATA

CONFIGURATION D-1B WING BEAVER-TAIL

SPEED (KT)	PROP RPM	K_t	K_q	J	η_o	ω	t	P_D (Full Scale HP)
9	362	0.118	0.0126	0.415	0.530	0.235	0.198	139
10	436	0.114	0.0139	0.418	0.537	0.165	0.216	268

K_t = Thrust Coefficient

K_q = Torque Coefficient

J = Advance Ratio

η_o = Open Water Efficiency

ω = Effective Wake Fraction

t = Thrust Deduction

P_D = DHP

TABLE 5
TABLE OF EFFICIENCIES

PIPE BEAVER TAIL

SPEED (KT)	η_o	η_b	η_r	t	ω	η_h	η_d
9	0.544	0.520	0.954	0.156	0.173	1.021	0.530
10	0.525	0.528	1.006	0.202	0.136	0.924	0.488

TABLE 6
TABLE OF EFFICIENCIES

WING BEAVER-TAIL

SPEED (KT)	η_o	η_b	η_r	t	ω	η_h	η_d
9	0.530	0.522	0.984	0.198	0.235	1.048	0.546
10	0.537	0.539	1.003	0.216	0.165	0.939	0.506

η_o = Open Water Propeller Efficiency

η_b = Behind Hull Propeller Efficiency

η_r = Relative Rotative Efficiency

t = Thrust Deduction

ω = Effective Wake

η_h = Hull Efficiency

η_d = Total Propulsive Efficiency

TABLE 7
KYNOC TRIALS WITH PIPE-BEAVERTAIL
(86.5 L.T. DISPLACEMENT)

SPEED (KT)	ENGINE* (RPM)	TORQUE (FT-LBS)	TAYLOR (WAKE)
8.606	1398	3335.7	0.193
9.109	1499	3795.5	0.173
9.567	1597	4292.6	0.158
9.895	1695	4805.7	0.130
10.217	1798	5350.0	0.095
10.366	1863	5696.8	0.069

TABLE 8
KYNOC TRIALS WITH WING-BEAVERTAIL
(86.5 L.T. DISPLACEMENT)

SPEED (KT)	ENGINE* (RPM)	TORQUE (FT-LBS)	TAYLOR (WAKE)
8.954	1403	2708.5	0.053
9.300	1499	3368.7	0.090
9.681	1602	3816.3	0.059
10.019	1695	4257.8	0.035
10.279	1790	4752.3	-0.004
10.580	1883	5189.7	-0.026

* Gear Ratio = 4.48/1

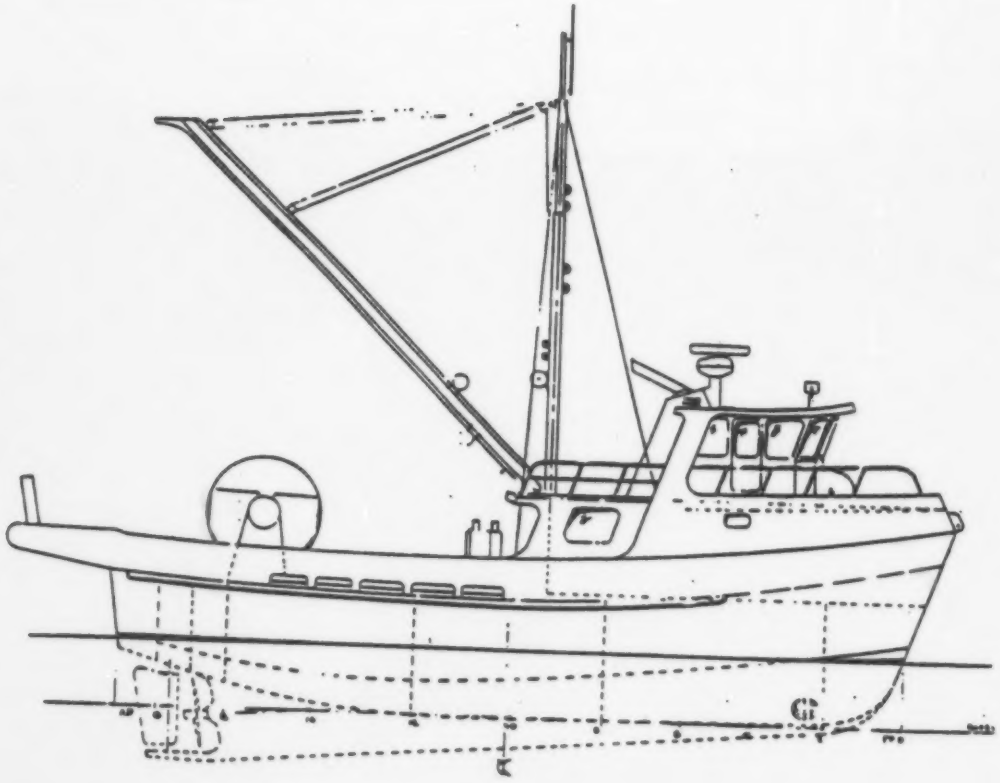


FIG. 1
PROFILE OF "KYNOC"

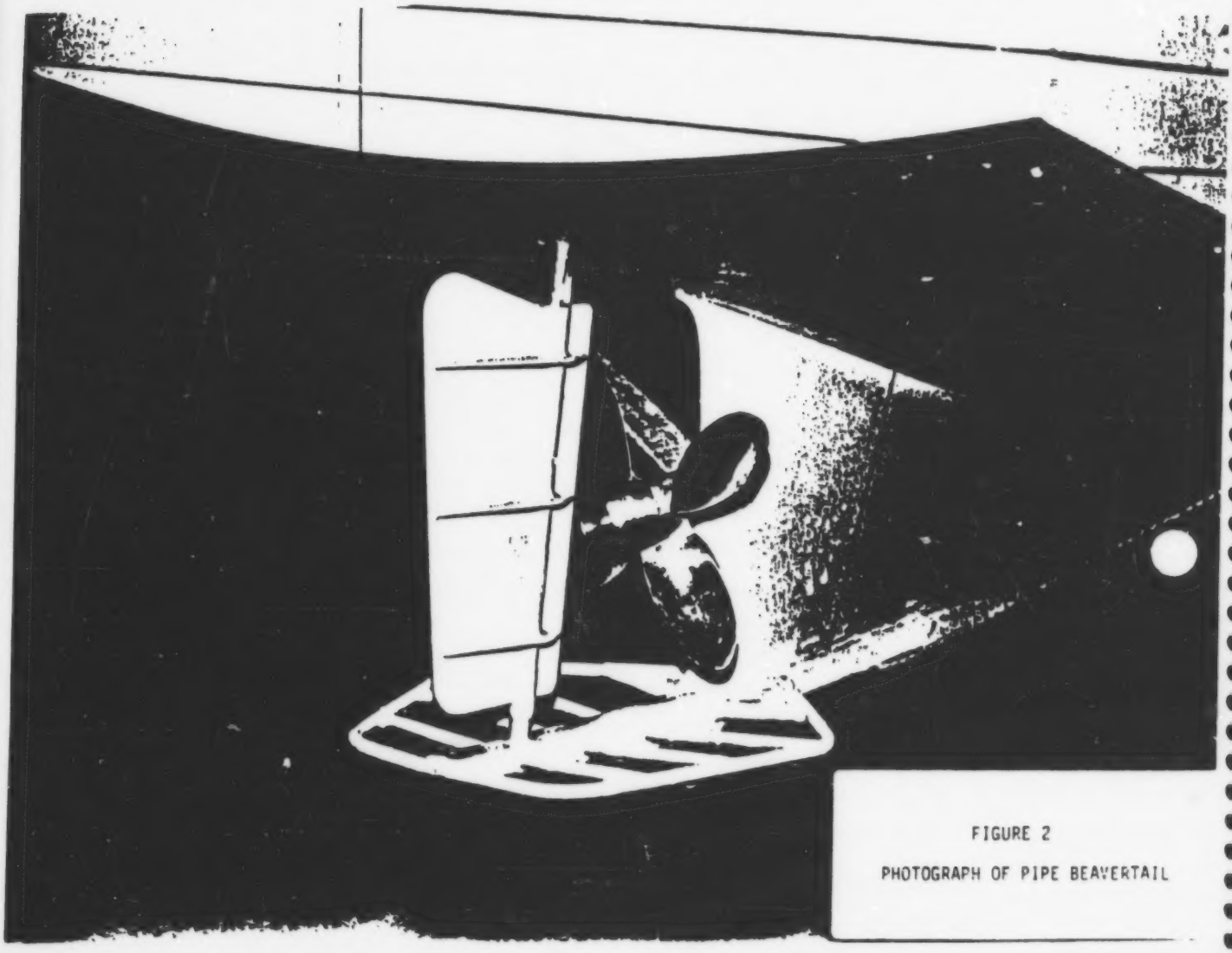


FIGURE 2

PHOTOGRAPH OF PIPE BEAVERTAIL

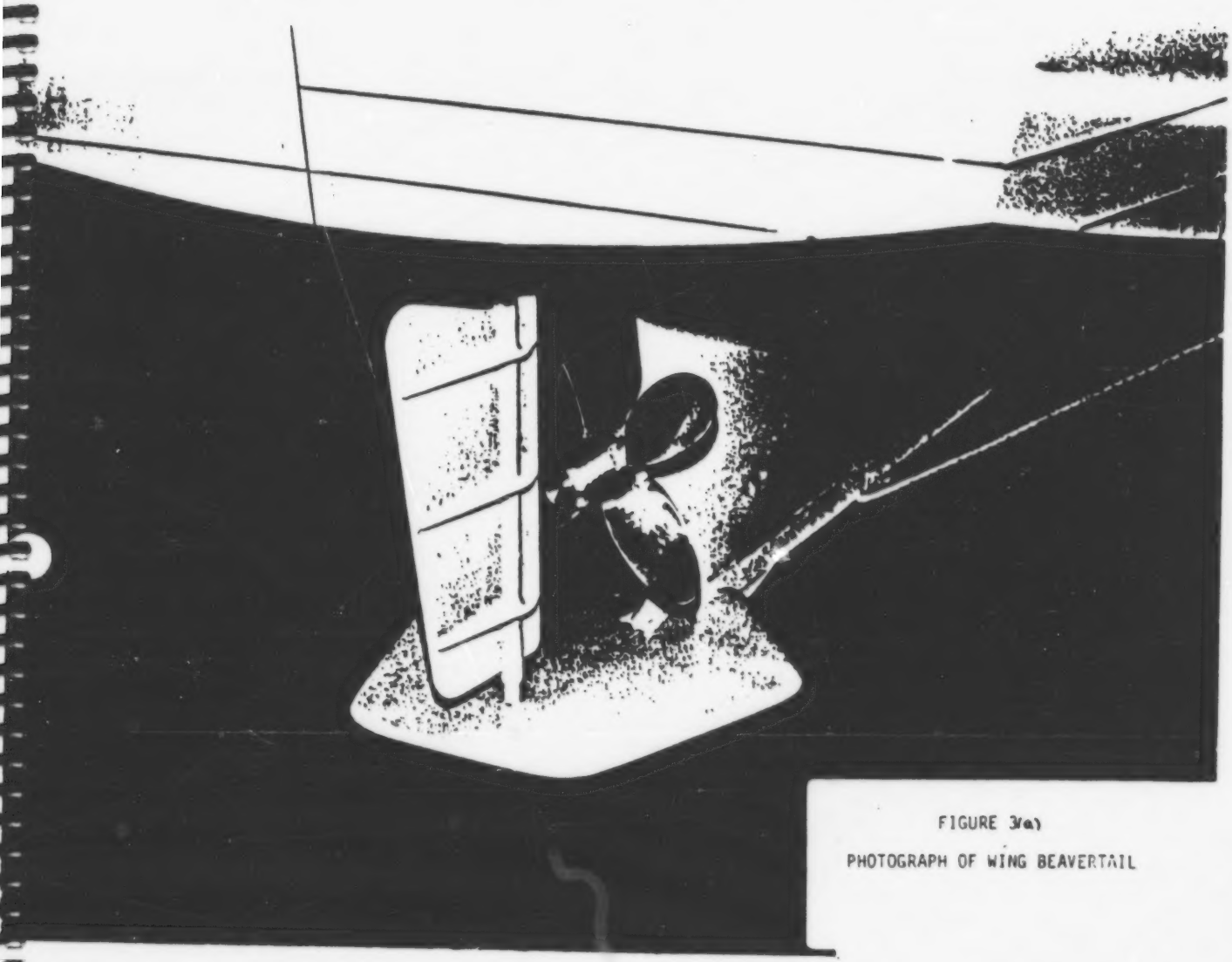


FIGURE 3(a)
PHOTOGRAPH OF WING BEAVERTAIL

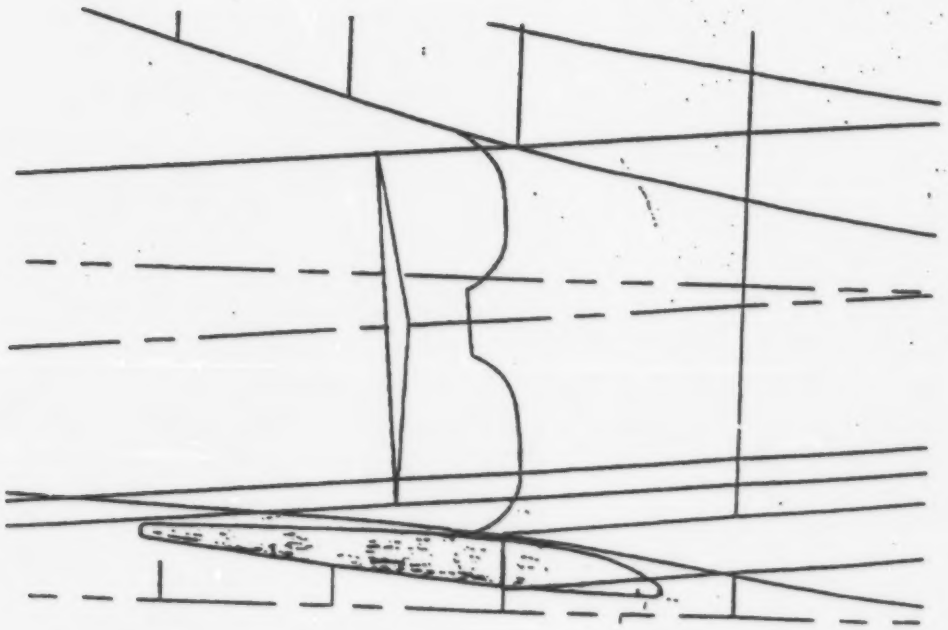


FIG 3b
SECTION OF WING BEAVERTAIL

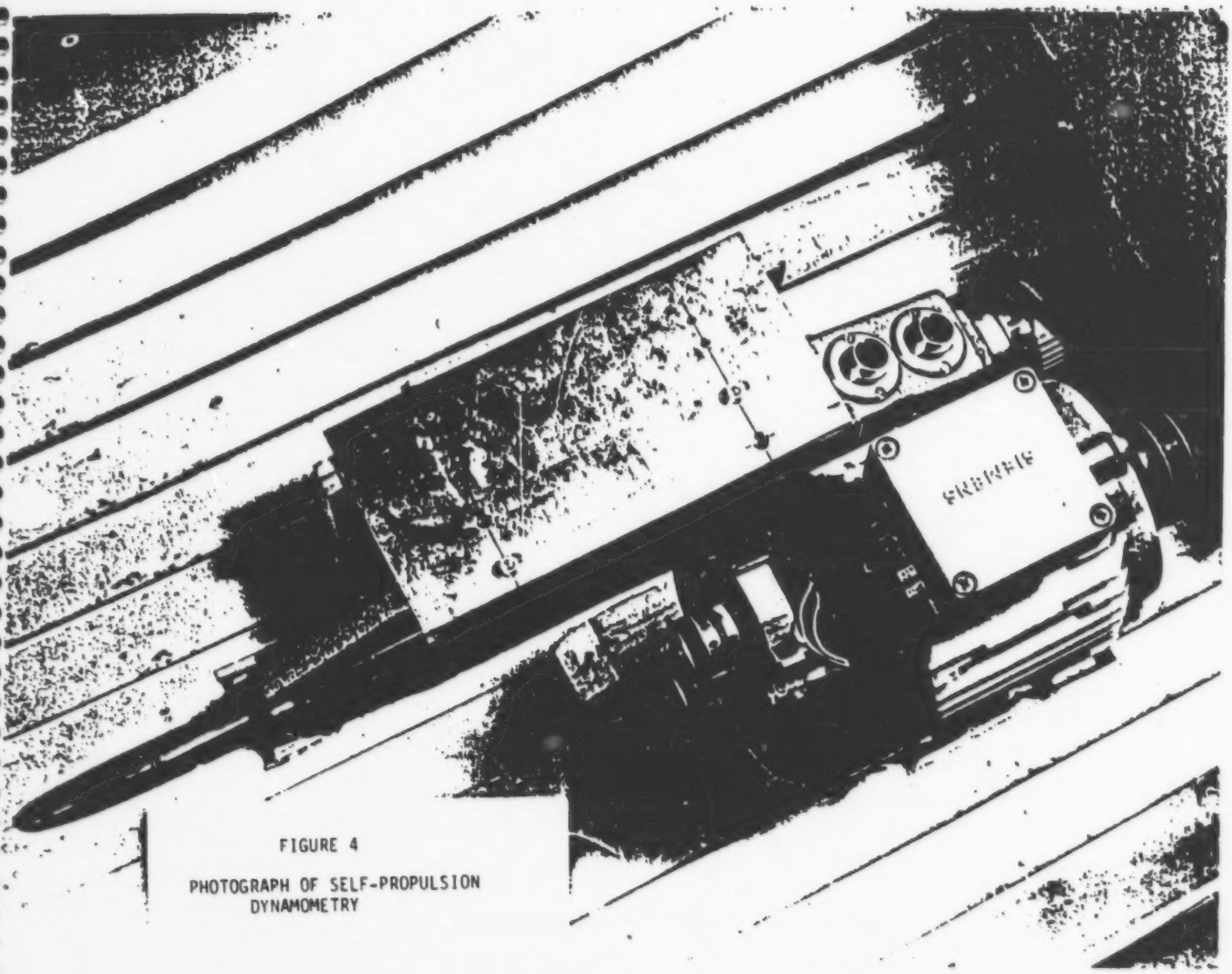


FIGURE 4

PHOTOGRAPH OF SELF-PROPULSION DYNAMOMETRY

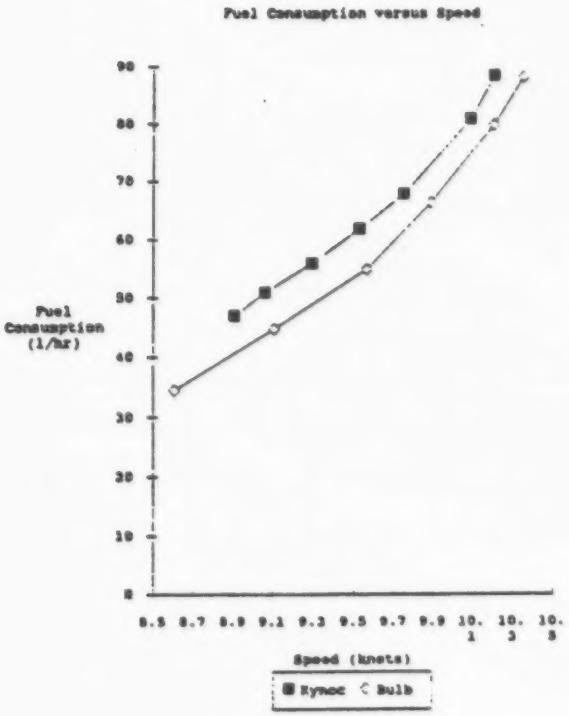
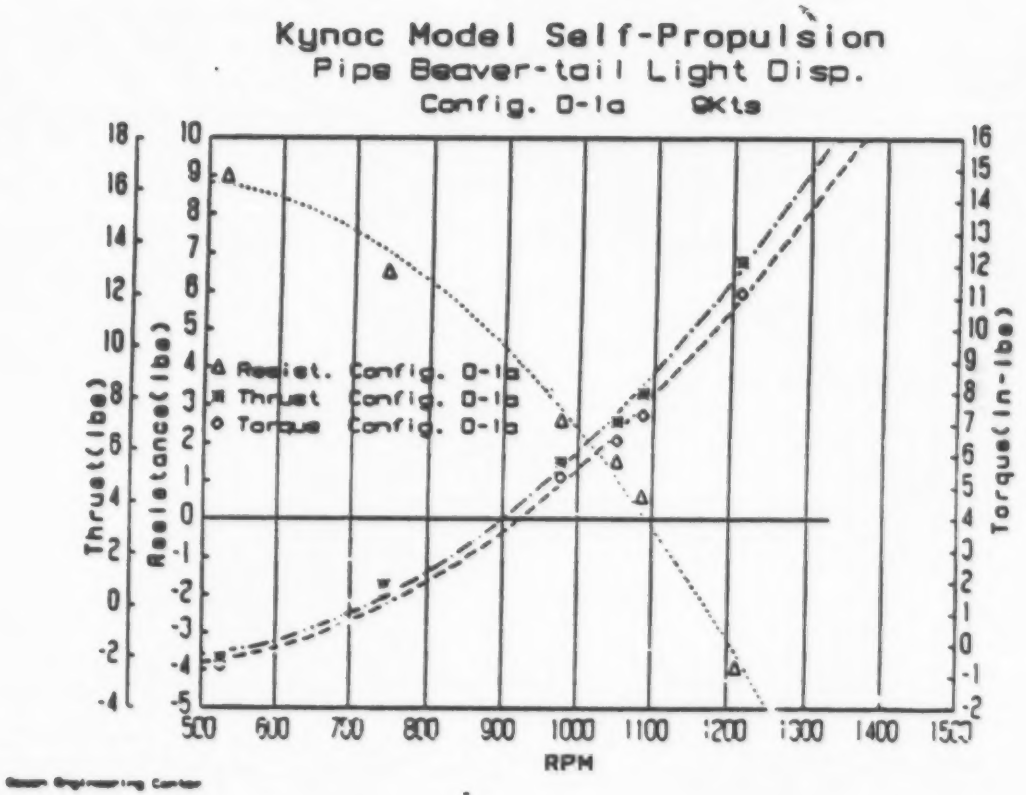
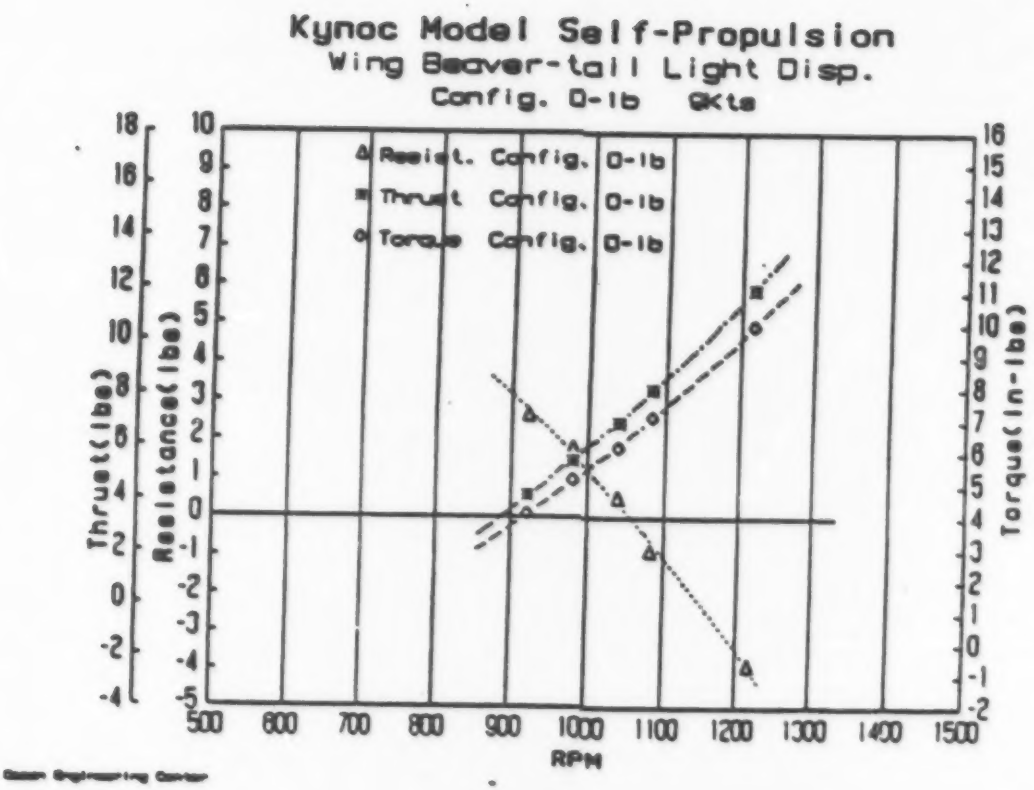
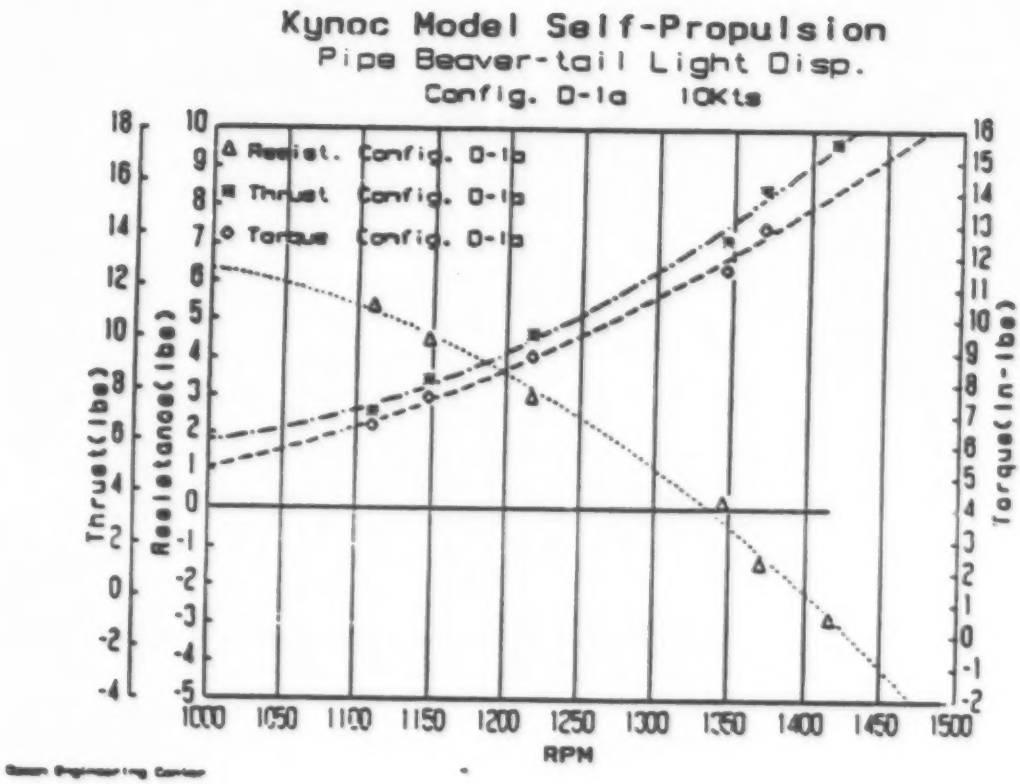
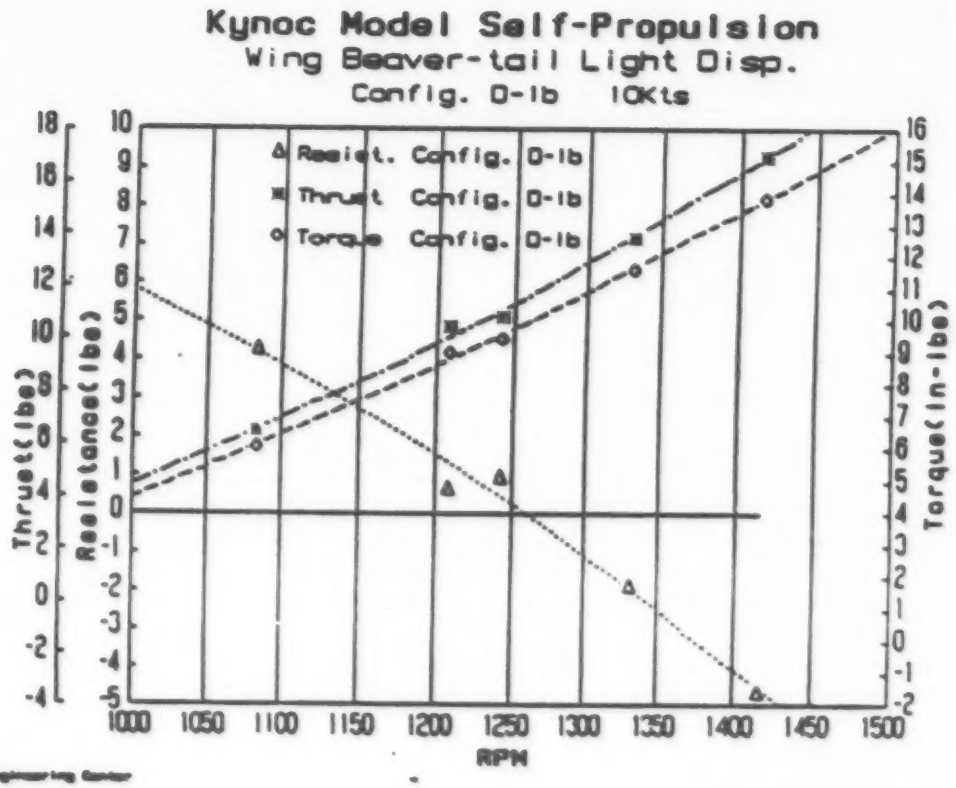


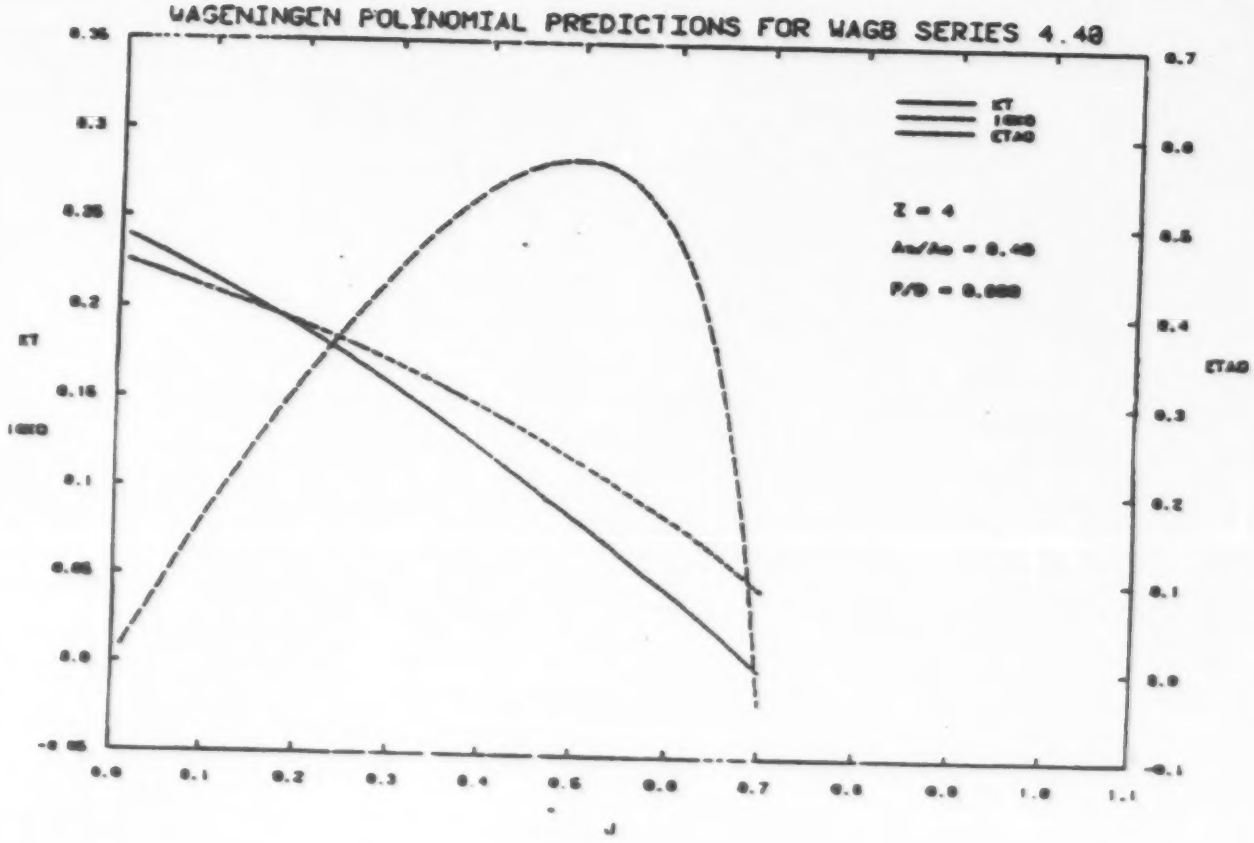
Figure 11 Fuel Consumption versus Speed from Sea Trials

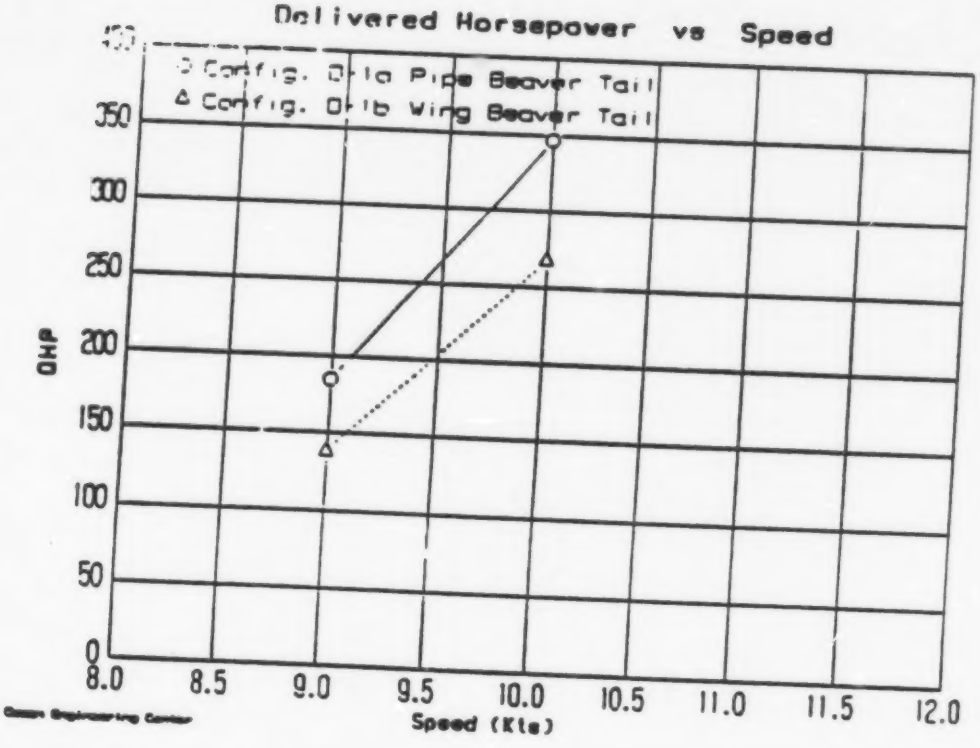

Kynoc Model Self-Propulsion
Pipe Beaver-tail Light Disp.
Config. 0-1a 9Kts
Thrust(lbs)
Resistance(lbs)
Torque(in-lbs)
RPM
Resist. Config. 0-1a
Thrust Config. 0-1a
Torque Config. 0-1a
500
600
700
800
900
1000
1100
1200
1300
1400
1500


Kynoc Model Self-Propulsion
Wing Beaver-tail Light Disp.
Config. 0-1b @Kts
Resist. Config. 0-1b
Thrust Config. 0-1b
Torque Config. 0-1b
Thrust(lbs)
Resistance(lbs)
Torque(in-lbs)
RPM
500 600 700 800 900 1000 1100 1200 1300 1400 1500

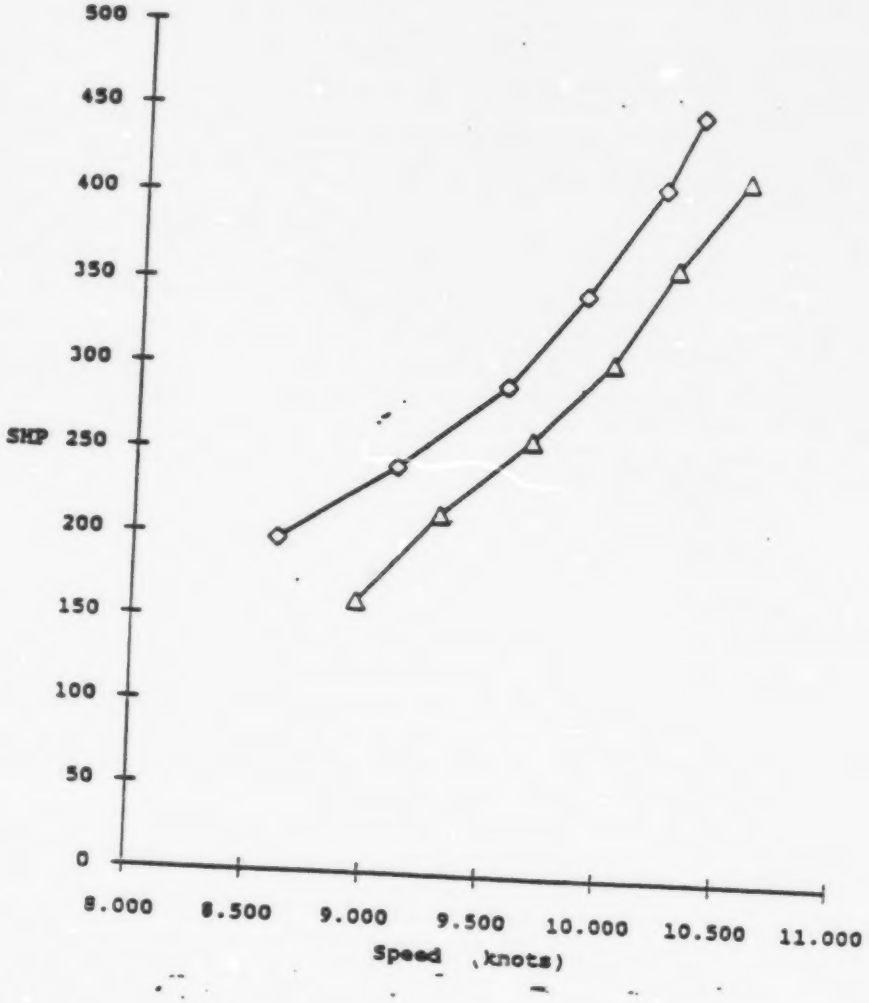

Kynoc Model Self-Propulsion
Pipe Beaver-tail Light Disp.
Config. D-1a 10Kts
Δ Resist. Config. D-1b
Thrust Config. D-1b
Torque Config. D-1b
Thrust(lbs)
Resistance(lbs)
Torque(in-lbs)
RPM
1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500


Kynoc Model Self-Propulsion
Wing Beaver-tail Light Disp.
Config. 0-lb 10Kts
Resist. Config. 0-lb
Thrust Config. 0-lb
Torque Config. 0-lb
Thrust(lbs)
Resistance(lbs)
Torque(in-lbs)
RPM
1000 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500


WAGENINGEN POLYNOMIAL PREDICTIONS FOR WAGB SERIES 4.40
KT
10KQ
ETAO
Z = 4
J


Delivered Horsepower vs Speed
○ Config. D-1a Pipe Beaver Tail
△ Config. D-1b Wing Beaver Tail
DHP
400
350
300
250
200
150
100
50
0
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
Speed (Kts)

Shaft Horsepower versus Speed for Kynoc



FULL SCALE TRIAL RESULTS
◇ PIPE BEAVERTAIL △WING BEAVERTAIL

APPENDIX E

INSTALLATION AND TESTING OF A BULBOUS BOW ON A CANADIAN FISHING VESSEL

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Department of Mechanical Engineering
University of British Columbia
Vancouver, British Columbia, Canada

Abstract

Although bulbous bows are now common on large ships and trawlers they are rarely used on vessels, such as seiners, less that 40 meters in length. A bulbous bow has been retrofitted to an existing 18 m fishing vessel *Kynoc* to show that a bulb can be effective in reducing the resistance and therefore full consumption of smaller vessels.

Model resistance tests results are presented which show how an optimum bulb design was found and the difficulties that were encountered. The instrumentation of full scale trials and results of these tests before and after the addition of bulb are presented. Measurement of the propeller shaft torque and engine fuel consumption show that bulbous bow reduced the fuel consumption by 13% at the design speed of 9.5 knots. Model tests in regular waves indicated that the bulbous bow also decreases the pitching motions and added wave resistance giving additional benefits to bulbous bow configuration.

Nomenclature

B = beam

$Displ$ = displacement (L.T.)

g = gravitational acceleration constant

L = length

R = resistance (lbs.)

R_{AW} = added wave resistance

$\mu_e = \omega_e\sqrt{\frac{L}{g}}$ = nondimensional encounter frequency

ρ = water density

$\sigma_{AW} = \sqrt{R_{AW}/\rho g^2 \frac{B^2}{L}}$

ω_e = encounter frequency

Introduction

Model testing at UBC on fishing vessel forms has shown that seiners can benefit from the addition of a side bulb [1]. A side bulb is similar to conventional bulbous bow except that it protrudes to the side rather than forward as with a conventional bulb (see figure 2). Seine fishermen prefer such a design since it is thought less likely to snag the seine net and does not increase the length of the vessel which is restricted by fishing licence regulations. Model experiments conducted on the UBC seiner series indicated about a 15% reduction in resistance at 10 knots.

To demonstrate the potential of a side bulb to fishermen, an EnerDemo project was funded by the Department of Energy Mines and Resources to install a side bulb onto an existing fishing vessel. The vessel chosen for the bulb installation was the 18.3 m drum seiner *Kynoc* designed by John Brandlmyr Ltd. (see figure 1). The vessel built in 1986 is typical of seiners currently being built. New vessels tend to have low length to beam ratios of about 3 and high displacement length ratios.

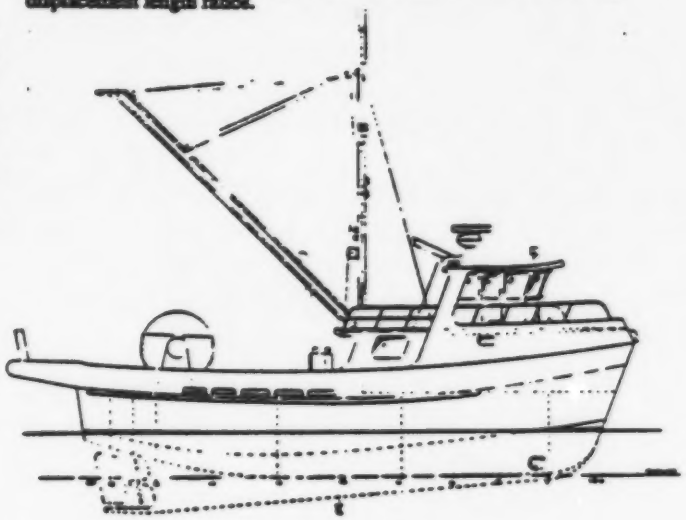

Figure 1 General Arrangement of *Kynoc*

Two side bulb shapes were calculated by a computer program developed at UBC[1]. The program used a hull form optimization technique developed by Hsiung [2] to minimize the total resistance a ship by optimizing the hull shape in the bow region. A 1/8 scale model was constructed with a removable bow section. The original bow and the two side bulbs were then resistance tested. When the side bulbs did not meet expectations three conventional bulbous bows were then constructed in addition to another side bulb design.

This paper gives the results from calm water resistance tests, wave cut analysis, seakeeping tests and full scale trials.

Side Bulb Tests

The mathematical methods used to develop the side bulb designs are described in reference [1]. Briefly the method optimizes an objective function which is the sum of the frictional resistance and the wave resistance. The frictional resistance is calculated by the ITTC-1957 formula and the wave resistance is calculated by Michell's Integral. A resistance equation that is a function of the hull offsets results from the use of test functions to approximate the hull. This allows standard mathematical procedures to be used to find the offsets that will give the minimum resistance. Constraints are used in the optimization to limit the offsets to practical values.

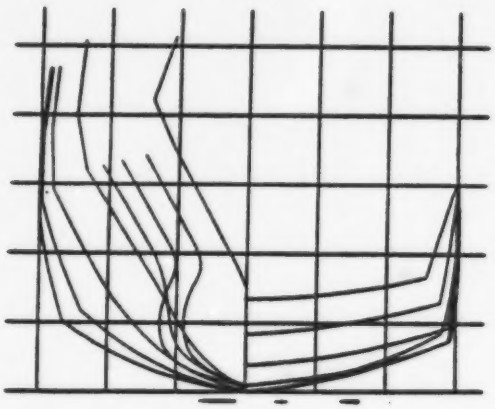

Figure 2 Body Plan of Side Bulb 1

Side bulb 1 (figure 2) was developed with the following constraints:

1 - hull offsets < 1/2 beam
2 - waterline slope < 34 degrees
3 - waterline area fixed
4 - 3.5% increase in displaced volume
5 - station 9.5 offsets < .4 times 1/2 beam

The program predicted a 10.8% reduction in total resistance. The offsets were faired by hand and a 1/8 scale wooden model was constructed. A second side bulb, with smaller waterline slopes after the bulb was also constructed.

Resistance tests were conducted at the BC Research Ocean Engineering Centre [3]. The model was free-to-trim and free-to-heave. Resistance, trim and sinkage were measured at speeds from 4 to 12 knots. The model was tested at two displacements 80.8 tonne and 136.5 tonne. The lower displacement is typical of the light running condition and the higher displacement of the loaded condition. The vessel operates about 90% of the time in the light running condition. When testing the bulbs the displacement was increased slightly so that the draft and trim remained constant.

When the resistance tests were run, longitudinal wave profiles were measured as the model passed a stationary wave probe. The wave probe was located 83.8 cm. from the centerline of the model and the model centerline of the model was moved 15 cm. from the centerline of the tank in order to increase the wave record time.

The resistance results for the side bulbs show that the side bulbs failed to reduce the total resistance of the model (figure 3). Bulb 1 increased the resistance more than bulb 2 and the increase in resistance is greater at low speeds. The wave profile data, however, shows that the wave height has been reduced by the side bulb (figure 4). The wave spectrum and wave resistance were computed by the longitudinal wave cut method [4]. The wave resistance was generally reduced and yet the total resistance was increased. This indicated that another component of resistance was increased by the bulbs.

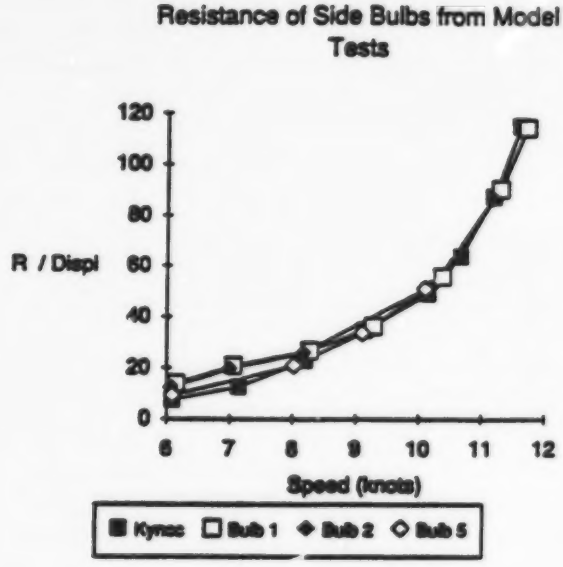

Figure 3 Resistance Results for Side Bulbs

Flow visualization experiments, using tufts, found flow separation was occurring after the bulb especially in bulb 1. Slow speed runs were used to determine the viscous drag form factor for each of the bulbs. The form factors were increased substantially by the bulbs. Increased viscous drag, it was concluded, caused the increase in resistance of the model with side bulbs.

Plasticine was added forward and aft of side bulb 2 to reduce the waterline slope in order to reduce the viscous drag. This did lower the form factor but did not lower the total resistance significantly. A new side bulb was then design (bulb 5) with smaller volume. The computer program predicted about a 5.5% reduction in resistance.

Bulb 5 had about the same resistance as the original hull (figure 3). The decrease in wave resistance was equally offset by an increase in the form factor. The increase in the form factor was less than for bulbs 1 and 2.

It is difficult to determine why the side bulbs were not successful on the *Kynoc* when they had been for the UBC series. The results may have been affected by the beam to draft ratio; it was larger for the *Kynoc* (4.06), than for the UBC series (3.39). Michell's Integral is best suited for thin ships and therefore the results for a smaller beam to draft ratio vessel should be more reliable. Also, the entrance angle of the *Kynoc* is greater than the UBC series which may cause difficulties due to the thin ship assumption of Michell's Integral. More research is required to determine when the optimization technique is valid for fishing vessel hull shapes.

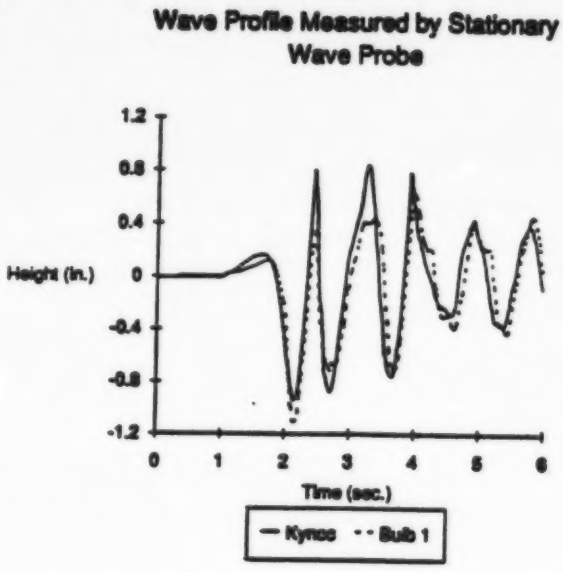

Figure 4 Wave Profile from Side Bulb Test

Cylindrical Bulb Tests

Three conventional cylindrical protruding bulb models were constructed (figure 5). The bulbs had a semispherical end which was connected to the hull by a cylindrical section. Each of the bulbs had a different radius: bulb 3 .42 cm, bulb 4 .57 cm and bulb 6 .69 cm. The center of the semisphere was located at the forward perpendicular for all three bulbs. As with the side bulbs, the models were ballasted so that the draft and trim remained constant.

The largest bulb, bulb 6, had about a 6 % reduction in resistance at 9 knots, however, at 10 knots the resistance was increased (figure 6). The smaller bulbs, bulb 3 and bulb 4, did not significantly change the resistance curve. The form factors for the cylindrical bulbs are much lower than for the side bulbs, but they are higher than for the original hull. The wave resistance calculations from the wave profiles showed that bulb 6 reduced the wave resistance by 16% and that the small bulbs did not reduce the wave resistance.

From the cylindrical bulb tests it was concluded that the large cylindrical bulb would be effective in reducing the resistance but the fuel savings would not cover the installation cost. Further testing was therefore conducted to determine if a longer cylindrical bulb would be more effective. The model of bulb 6 was modified so that four 33 cm cylindrical extensions could be added between semispherical end and the section that joins the bulb to the hull. This allowed the bulb to be extended forward in 33 cm increments to a total of 1.33 m. The bulbs are labelled in order of increasing length: bulb 6.2, 6.3, 6.4 and 6.5 respectively. Bulb 6.2 extended forward the same distance as the bow overhang so did not increase the length of the vessel. Bulb 6.3, 6.4 and 6.5 extended forward of the bow and thus would not ordinarily be allowed by present fishing licence regulations since they would increase the measured length.

The resistance results for the extended bulbs in the light condition show a substantial reduction in resistance as the bulb length is increased (figure 7). The resistance at 10 knots for bulb 6.5 is 20% less than the original hull. The reduction in resistance is over the entire operating range of the vessel. For the loaded condition the changes in resistance are not as large and are greater at lower speeds. At a typical operating speed of 9 knots the resistance of bulb 6.5 is 8% lower than the original hull.

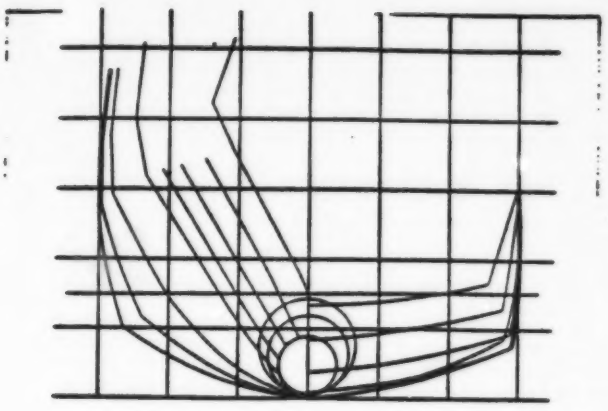

Figure 5 Cylindrical Bulbs

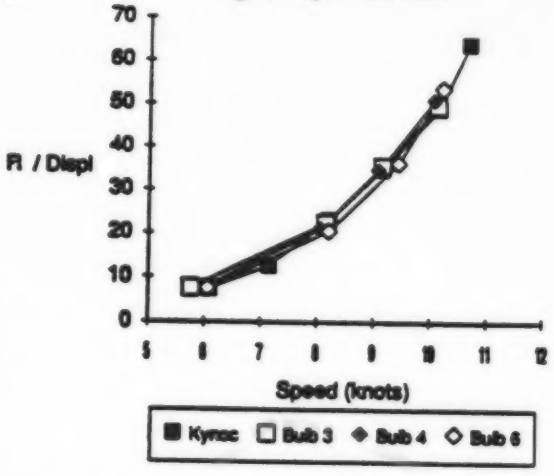

Figure 6 Resistance Results for Cylindrical Bulbs

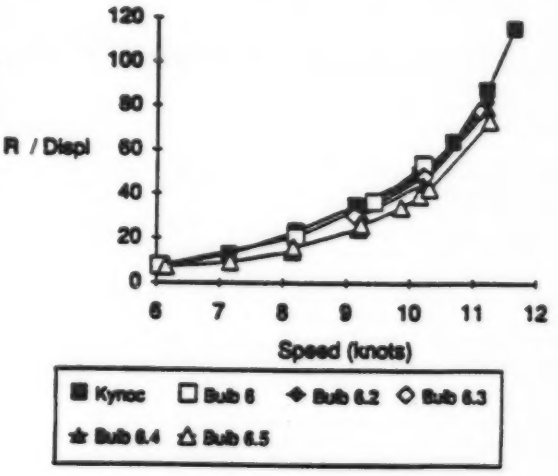

Figure 7 Resistance Results for Extended Cylindrical Bulb

Seakeeping Model Tests

After consultations with the owner of the *Kynoc*, Bill Wilson, bulb 6.5 was selected for further testing. Seakeeping model tests were conducted for regular waves in head seas. The model was tested at 10 encounter frequencies, with and without bulb 6.5. Heave and pitch response were measured and the resistance was measured.

The results for added resistance show that the bulb significantly reduced the added resistance in waves (figure 8). The resistance was reduced mainly at the higher encounter frequencies by about 30%. The resistance was slightly greater for the bulb at the low frequencies. The bulb was found to reduce the pitch amplitudes by about 20% at all frequencies. The bulb increased the heave amplitude at low frequencies and decreased it at higher frequencies.

The seakeeping tests of the bulb proved that the bulb would have a further benefit to the *Kynoc* in waves to that in calm water. The bulb decreases the resistance in waves and reduces the pitching motions.

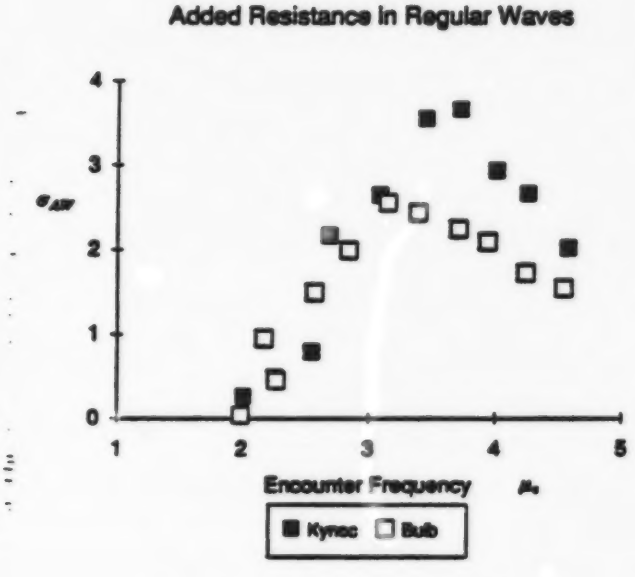

Figure 8 Added Resistance in Waves of *Kynoc*

Full Scale Trials

To further confirm the effectiveness of the bulbous bow, full scale trials were conducted before and after the installation of the bulb. The bulb was fabricated out of aluminum by Shore Boat Builders and welded to the keel and the exterior of the hull. The trials were conducted on a measured .5 mile course on the Fraser river [5].

The vessel was powered at constant RPM up and down the river between two marker buoys and the times between the marks was used to calculate the speed. The effect of the current was accounted for by averaging the against current speed and the following current speed.

The engine RPM and fuel consumption were measured with a Microfuel Systems fuel meter [6] and the shaft torque was measured by strain gauges glued to the propeller shaft. An integrated strain gauge amplifier and FM/FM transmitter was used to send the strain gauge signals from the shaft to the data acquisition equipment.

The torque meter was calibrated while the vessel was up on ways being fitted with a bulbous bow. Torque was applied to the shaft by a 2 m wrench fitted to the propeller nut. A chain hoist with a .5 tonne load cell was attached to the end of the wrench and anchored to the ways.

The trials without the bulb were done a week before the bulb was installed. The bulb installation took one week and the trials with the bulb were done the following week. No weight was moved between tests except 3400 liters of water was added to the forward tank to restore the vessel to the same trim as before the bulb.

The vessel was ballasted to the light condition tested in the model tests. The vessel had 10 cm trim by the bow more than in the model test. The owner indicated that this was the usual operating trim so the test were conducted at this trim.

The trials were conducted at six engine RPMs from 1400 to 1850. At each RPM, four runs were made; two in each direction. The bulb increased the attained speeds at all RPMs. At 1600 RPM the speed increased .25 knots and at 1850 RPM the speed increased .15 knots.

In all cases tested, the fuel consumption rate was less with the bulbous bow than the original hull. At 9.5 knots, fuel consumption was reduced 13% (figure 9). The results for the shaft horsepower show good agreement with the fuel consumption values. The power was reduced 13% at 9.5 knots.

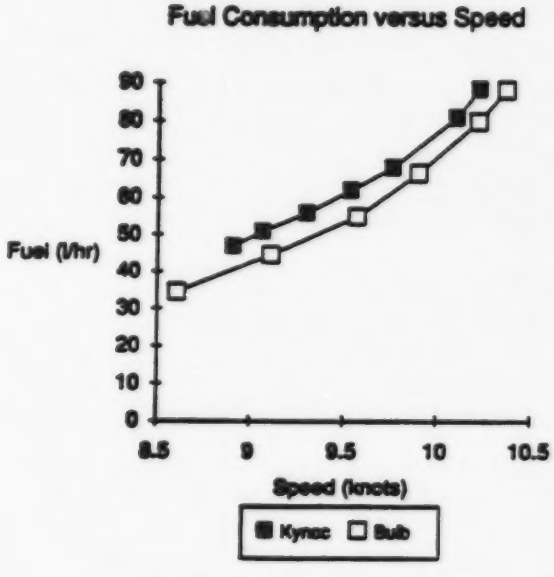

Figure 9 Fuel Consumption versus Speed of *Kynoc*

Conclusions

Model testing and full scale trials on the fishing vessel *Kynoc* have proven that a bulbous bow can be an effective way to reduced fuel consumption on a medium sized low L/B fishing vessel. This project gave the rare opportunity to do both model testing and full scale testing of a fishing vessel. Although the side bulbs were not as effective as previous model tests, probably due to the smaller beam to draft ratio of *Kynoc*, further research is recommended into the feasibility of side bulb designs.

Acknowledgments

The authors would like to thank EMR, DFO, and NSERC for funding the research program. They would also like to thank Bob McIlwaine for project management, BC Research Ocean Engineering Centre for model testing, John Avis for engineering assistance and especially Bill Wilson the owner of the *Kynoc* for his full cooperation in the project.

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2 Hsiung, C.C., "Optimal Ship For Minimum Total Resistance", *Journal of Ship Research*, Vol 28, No. 3, Sept. 1984, pp. 163-172.

3 Roddan, G., "Model Tests of the *Kynoc*: A Hull Optimization Program", BC Research Report No. 6-02-922-1, 1989.

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5 Avis, J., and McGreer, D., "Full Scale Instrumentation and Testing of the Fishing Vessel 'Kynoc'", Internal Report, Mechanical Engineering UBC, 1989.

6 Burchet, R., "Vessel Management: The Second Generation", International Fisheries Energy Optimization Workshop, DFO Canada, Vancouver, BC, 1989.

Part B

FINAL REPORT ON THE DESIGN, INSTALLATION AND FULL-SCALE TESTING OF A BULBOUS BOW AND WINGED-TYPE NET GUARD ABOARD THE FV "KYNOC"

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
July, 1989

Funding for this project was
provided under the Enerdemo Program.

1.0 INTRODUCTION

The purpose of this project is to demonstrate to the commercial fishing industry how fuel savings can be achieved through the installation of bulbous bows and hydrodynamic net guards.

Studies on fishing vessel hull forms and ways to improve their efficiency have been conducted at the Department of Mechanical Engineering, University of British Columbia, for several years. The results of computer analysis and model testing of various fishing vessel hull forms indicated that substantial fuel savings through the incorporation of bulbous bows.

Brandlmayr Marine Ltd. (formerly John Brandlmayr Ltd.), in association with Shore Boat Builders Ltd., developed and carried out preliminary tests on a winged-typed net guard (commonly called a "Beaver tail") to replace the high drag pipe frame beaver tails normally installed on West Coast seiners. The Enerdemo project currently underway involved the design and model testing of several bulbs to permit selection of an optimal bulb for installation, full-scale trials, and demonstration aboard the 60-foot seine boat "Kynoc", owned by the Sunshine Fishing Company Ltd. Model testing of a winged-type beaver tail was also completed with a view to optimising the design for installation aboard the Kynoc.

This summary report, in conjunction with its two annexes, provides the results of the design, model testing and full-scale trials phases of the project.

2.0 DESIGN

2.1 BULBOUS BOW

Design optimization for the bulbous bow was carried out by Pacific Marine Technologies Inc. An initial side bulb design was generated which would result in a six per cent reduction in hull resistance. In view of the much greater resistance reductions obtained in the UBC parent hull, optimization was continued to obtain a bulb design which would achieve 10 per cent savings. The resulting design presented a fairly radical profile, so the decision was made to produce models of the computer-generated bulb and a modified version with a less severe profile.

As a result of the model testing program described below, which resulted in the abandonment of the side bulb design, further design work was continued in conjunction with the model testing to optimize a standard bulb for full-scale demonstration aboard the Kynoc.

2.2 WINGED-TYPE NEW GUARD (BEAVER TAIL)

The winged-type beaver tail design was provided by Brandlmayr Marine based on earlier designs which had been tested to a very

limited degree aboard a small seiner. This design was model tested for comparison against a standard beaver tail, and further design changes were made by Brandlmayr Marine for an improved version.

3.0 MODEL TESTING

Model testing was carried out by the B.C. Research Ocean Engineering Centre. A detailed report on the model testing phase is provided in Annex I (Final Report, Model Tests of the "Kynoc", A Hull Optimization Program, prepared by G. Roddan, B.C. Research).

3.1 SIDE BULBS

Both versions of the side bulb generated during the design phase produced flow separation near the hull with no overall reduction in resistance. Several modifications were made, but further testing resulted in no significant improvements. It was determined, contrary to the computer predictions, that the side bulb was not compatible with the "Kynoc's" hull form.

3.2 STANDARD BULBS

Work then commenced on the testing of two standard bulb configurations, designed so that the vessel's regulation length and anchoring operations would not be affected. These designs produced better flow patterns, but achieved no measurable resistance reduction over the unmodified hull. Further designs, with no length restrictions, were tested and optimized to produce a final bulb design (bulb 6-5), which resulted in a reduction in resistance of approximately 22% at 9 knots in comparison with the original bow in the light running condition. In the loaded condition, the decrease in resistance of 6.5% at 9 knots was much smaller, but of much less importance as the vessel normally operates in the light condition. A more uniform wake distribution was also produced by the bulb. As a result, this bulb was selected for further testing and installation aboard the "Kynoc".

During sea keeping tests conducted with the selected bulb it was found that the behaviour of the vessel was improved, with reductions of added resistance, pitch, and vertical bow acceleration in head seas.

3.3 BEAVER TAIL

Self-propulsion tests were performed on the model with the selected bulb to compare the resistances of the winged-type beaver tail versus the conventional pipe frame version. The hydrodynamic winged version achieved a 22% saving in shaft horsepower over the conventional model at 10 knots. These results appear to be compatible with the limited tests conducted earlier by Brandlmayr Marine on the small seiner.

4.0 HULL MODIFICATIONS TO FV "KYNOC"

4.1 BULBOUS BOW

The full scale version of bulb 6-5 was fabricated at Shore Boat Builders Ltd. and installed aboard the "Kynoc" at Progressive Marine Ltd. Costs for the bulb installation were as follows:

- fabrication, Shore Boat Builders Ltd.	$10,800
- installation, Progressive Marine Ltd.	3,786
	$14,586

4.2 BEAVER TAIL

Based on the earlier trials and model test results of the winged-type beaver tail, Brandlmayr Marine Ltd. developed an improved design and the decisions was made to install this newer version onboard the "Kynoc".

Fabrication and installation of the beaver tail was completed at Progressive Marine.

Costs for the beaver tail were as follows:

- design & installation coordination Brandlmayr Marine Ltd.	$ 700
- fabrication & installation Progressive Marine Ltd.	11,091
	$11,791

5.0 FULL SCALE TESTING AND MONITORING

The full scale testing and monitoring phase of the project was conducted by the Department of Mechanical Engineering, University of B.C. A detailed report on the testing procedures and the results are provided in Annex II (**Full Scale Instrumentation and Testing of the Fishing Vessel "Kynoc"**, prepared by John Avis and Dan McGreer, UBC Mechanical Engineering).

5.1 MONITORING EQUIPMENT

To measure fuel consumption and relevant parameters , a Microfuel Systems Inc. EMS1000 Fuel Management System was installed in the "Kynoc" along with a torque meter and data aquisition system provided through UBC. To measure the vessel's sea keeping performance, accelerometers were also installed by UBC.

The fuel management system was installed and calibrated in February, 1989, in time for use during the 1989 roe herring fishery. The system performed satisfactorily, and through the direct fuel consumption information available, the owner felt that annual fuel savings of approximately $3,000 to $4,000 could be achieved through this equipment alone.

5.2 FULL SCALE TESTS

5.2.1 Hull Without Modifications

Prior to installation of the bulbous bow, the vessel's hull, fitted with a standard pipe frame beaver tail, was docked and cleaned. Speed trials of the "Kynoc", in her normal light condition, were then conducted over a measured half-mile section of the Fraser River and measurements taken with the fuel meter and torque meter. The results of these trials are presented in Figures 1 and 2, provided from UBC, and show good comparison with the computer predicted fuel consumption for hull without bulb in Figure 3, also provided through UBC. It should be noted that the computer generated results do not take into account the pipe frame beaver tail.

5.2.2 Hull With Standard Bulb

Immediately following installation of the bulb, speed trials were again conducted on the Fraser River with the "Kynoc" in the light condition. The results are shown in Figures 1 and 2 and again show good comparison with the computer generated results in Figure 3. In all cases tested, as reported by UBC, the fuel consumption rate at a fixed speed was less for the hull with bulbous bow than for the original hull. It should be noted that a pipe frame beaver tail was fitted for both hull configurations. At 9.5 knots fuel consumption was reduced 13% as a result of the bulb installation.

5.2.3 Hull With Bulb and Winged-Type Beavertail

On completion of the installation of the new beaver tail, the final series of full scale trials was conducted on the measured half-mile. The results are again shown in Figures 1 and 2, but there is no computer generated data of the hull with beaver tail for comparison.

Through the addition of the hydrodynamic, winged-type beaver tail, the fuel consumption at 9.5 knots was reduced a further 12% giving a total fuel saving of 23% at this speed.

6.0 PRELIMINARY ECONOMIC ANALYSIS

Based on the full scale trials a preliminary economic analysis can be made to estimate the vessels fuel savings and payback for the installation costs of the bulbous bow and the winged-type beaver tail. It should be noted, however, that these trials were conducted over short periods of time in a short section of the Fraser River, under fair weather conditions. Predictions made on the trials may not accurately reflect the annual fuel savings that will be obtained during fishing operations under varying weather and sea conditions.

At an annual fuel bill of approximately $30,000 a projected payback of the bulb and beaver tail installations can be calculated as follows:

Projected Annual Payback

estimated average speed	9.5 knots
fuel saving @ 80% of 23% (allowing for hull fouling and varying conditions)	18.4%
bulb installation	$14,586
beaver tail installation	11,791
total cost	$26,377
annual fuel cost savings 18.4% x $30,000	$5,520/year
simple payback = $\frac{\$26,377}{\$5,520/yr} = 4.78$	5 years

It is possible that the fuel savings may more closely approximate the 23% figure obtained during the trials, and that future installations for similar vessels may have a lower capital cost which would result in a shorter payback. It should be noted that in the case of trawlers, and combination seiner/trawlers, with longer operating seasons and much larger fuel bills, the payback period would also be improved.

7.0 CONCLUSIONS

The results obtained in the project so far have considerably exceeded the initial expectations. It is anticipated that with further confirmation during fishing operations, that other fishing vessel owners will take advantage of either or both modifications. Although there may be reluctance on the part of some owners to install large bulbs on their vessels, it is expected that there will be a large number of retrofits of the winged-type beaver tail on seiners and that this feature will become the norm on new seine hulls.

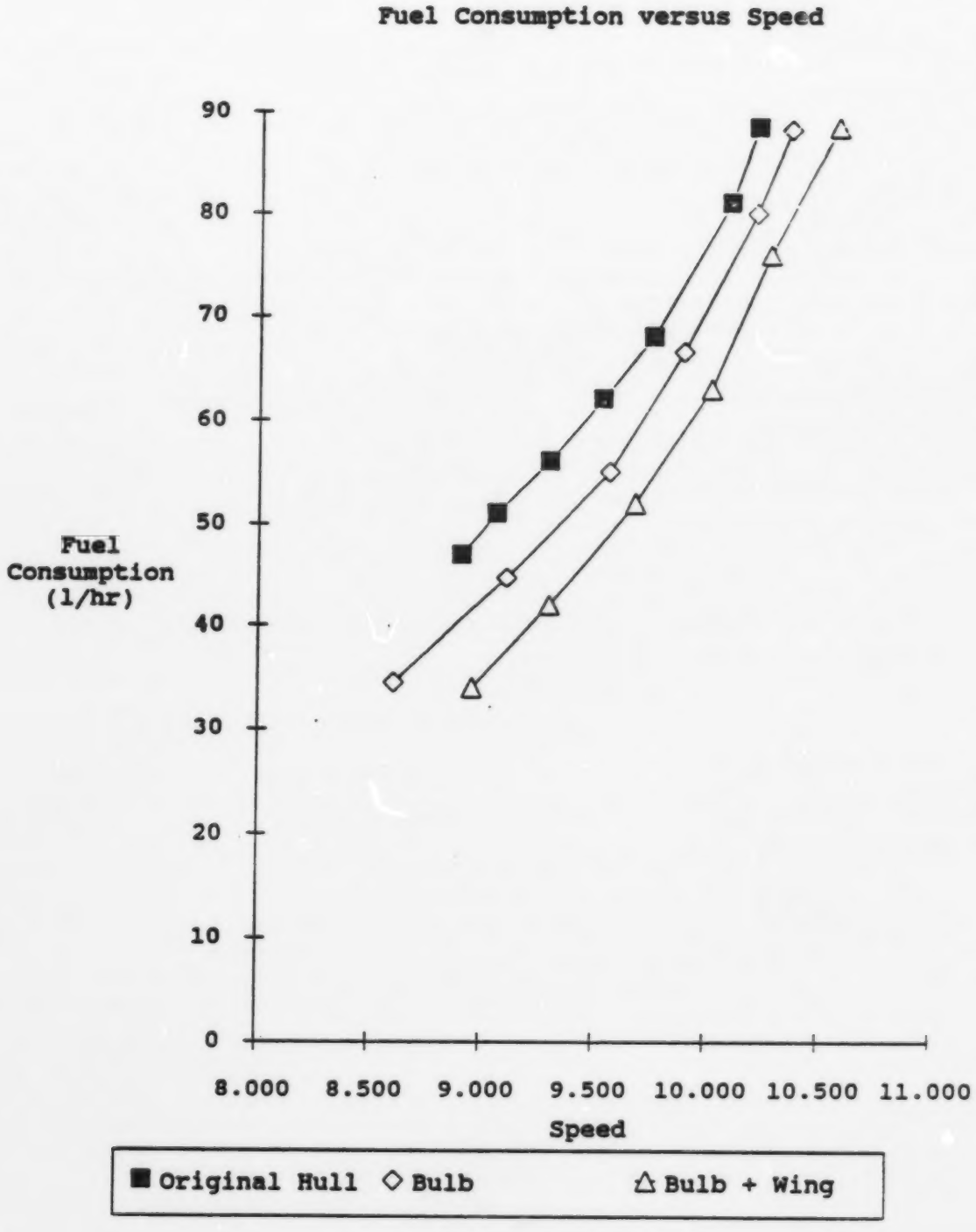
Fuel Consumption versus Speed
90
80
70
60
50
40
30
20
10
0
Fuel Consumption (l/hr)
8.000
8.500
9.000
9.500
10.000
10.500
11.000
Speed
Original Hull
Bulb
Bulb + Wing

Figure 1

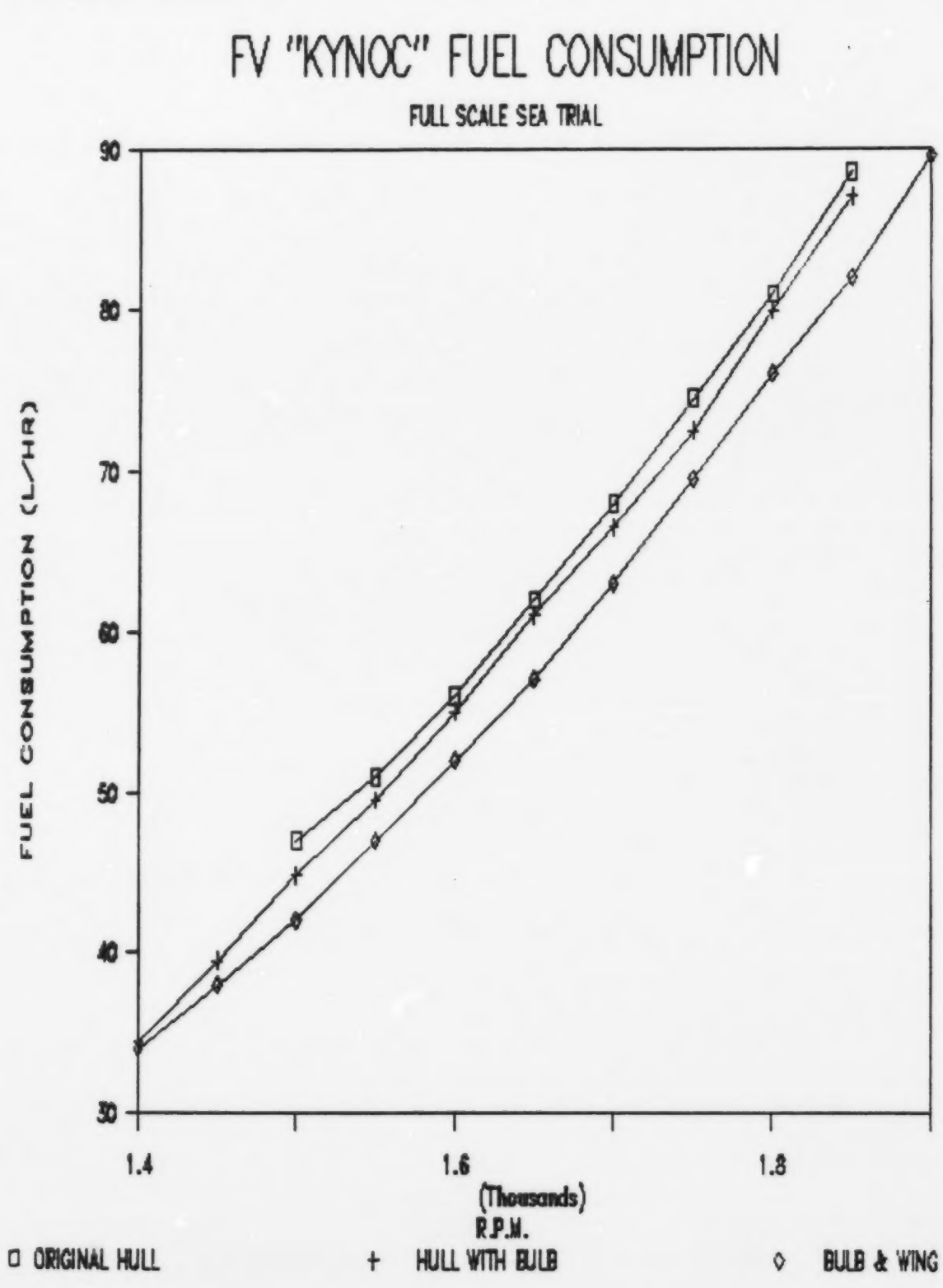
FV "KYNOC" FUEL CONSUMPTION
FULL SCALE SEA TRIAL
FUEL CONSUMPTION (L/HR)
90
80
70
60
50
40
30
1.4
1.6
1.8
(Thousands)
R.P.M.
□ ORIGINAL HULL
+ HULL WITH BULB
◊ BULB & WING

Figure 2

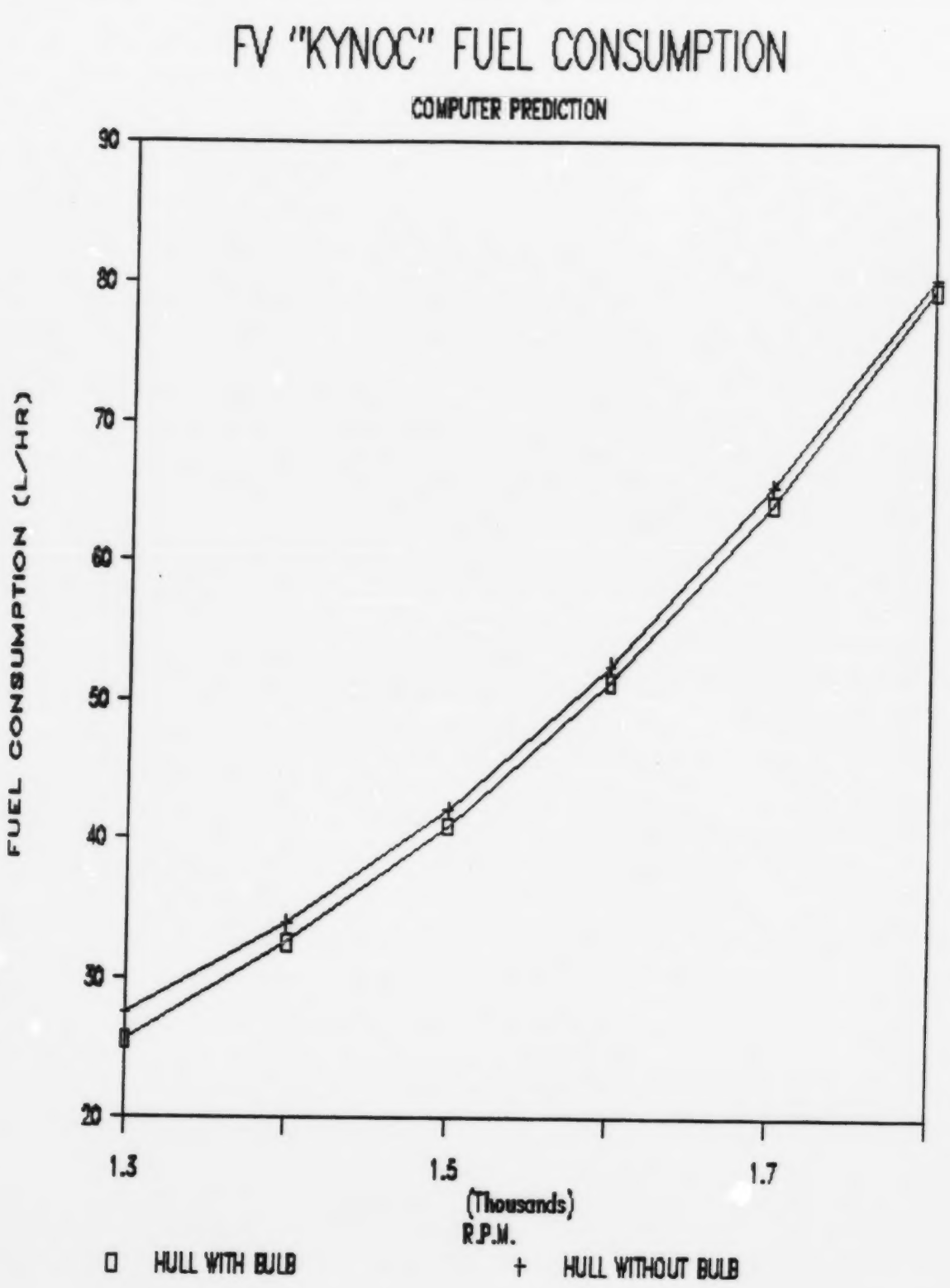
FV "KYNOC" FUEL CONSUMPTION
COMPUTER PREDICTION
FUEL CONSUMPTION (L/HR)
90
80
70
60
50
40
30
20
1.3
1.5
1.7
(Thousands)
R.P.M.
HULL WITH BULB
HULL WITHOUT BULB

Figure 3